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THE MACROINVERTEBRATE FAUNA AND THERMAL REGIME OF LAKE WABAMUN, A LAKE RECEIVING THERMAL EFFLUENT

by

JOSEPH BRASEN RASMUSSEN

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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EDMONTON, ALBERTA
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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "The macroinvertebrate fauna and thermal regime of Lake Wabamun: a lake receiving thermal effluent," submitted by Joseph Brasen Rasmussen in partial fulfillment of the requirements for the degree of Master of Science.

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Date Dec 1, 1978

ABSTRACT

Studies on the composition of benthic and plant-dwelling macroinvertebrate communities in Lake Wabamun were carried out from May, 1972 to September, 1975. During the study period, heated effluents from two power generating stations were being discharged into the lake. Year-around studies of temperature regimes accompanied the studies of macroinvertebrate animals and were carried out in the vicinity of both thermal discharges and in unaffected areas of the lake as well.

Lake Wabamun is a shallow (mean depth 5.4 m, maximum depth 11.5 m) moderately eutrophic lake, which does not stratify during summer months. Thermal effluents were being discharged into shallow, littoral bays and extremely heavy growths of aquatic macrophytes were evident in those areas throughout the summer periods. Pronounced temperature elevations (5°C-8°C at the substrate) were recorded at stations situated in the immediate vicinity of discharges. Throughout most of the area of bays which receive heated effluents, the temperature elevation was mostly confined to the surface waters and was very slight (usually $< 2°C$) at the substrate.

The benthic fauna of most of the lake's mud sediments was dominated by *Polypedilum nubeculosum*, *Cladotanytarsus* spp., and *Tanytarsus* spp.; and, by Saether's (1975) criteria it would be characteristic of a state of moderate eutrophy. The benthic fauna that characterized bays receiving thermal discharges, was dominated by *Chironomus* spp. (usually the large species *C. plumosus*, *C. atroviridis* and *C. tentans*) and indicated a much greater degree of

eutrophy. The annual maximum of standing crop of benthic chironomids was much higher in those areas than in areas that supported the *Polypedilum-Cladotanytarsus-Tanytarsus* benthic assemblage.

Stations in the immediate vicinity of thermal discharges yielded far fewer species than did unheated control stations of the same depth. In addition to reduced species diversity, notable alterations in the structure of the benthic and plant-dwelling animal communities were observed in heated areas. Tubificid oligochaetes dominated the benthos and gastropod molluscs far outnumbered chironomid larvae on the vegetation. *Gammarus lacustris,* a cold stenothermic amphipod, was absent or only intermittently present throughout the heated areas.

Mechanical macrophyte harvesting and removal was carried out in the littoral areas of Kapasiwin Bay from June-August of 1972-75. This bay receives the discharge from the Wabamun power station. The application of the procedure was accompanied by a shift in species composition of the benthic fauna (towards dominance by smaller *Chironomus* spp. and *P. nubeculosum*) within Kapasiwin Bay, and by a decrease in the annual maximum of standing crop of benthic chironomids. These changes were accompanied by a pronounced decrease in the plant-litter content of the mud.

Macrophyte removal from Kapasiwin Bay was also accompanied by an increase in the numbers and diversity of plant-dwelling larvae of the subfamily Orthocladiinae.

Factors influencing the species composition of benthic and plant-dwelling macroinvertebrate communities, and, the manner in which such factors might be influenced by increased water temperatures, are discussed.

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INTRODUCTION

Temperature is a physical variable which affects biological processes at all levels. The biochemistry, physiology, and behaviour of ectothermic organisms are all very sensitive to the thermal regime under which the organisms live. Besides the basic effect that temperature exerts on the rates of metabolism, assimilation, digestion, *et cetera*, it serves as an important cue in governing the timing of many events or phases in the life cycles of plants and animals. Although temperature as a seasonal cue rarely acts along, there are a great many species which appear never to reproduce above or below certain temperatures. Cooper (1965) found that *Hyalella azteca* (Saussure) would not breed at temperatures below 10°C, and Konstantinov (1958a) found that the chironomid species that he studied had critical temperatures below which they would neither develop nor emerge. Bousfield (1958) reported that breeding by *Pontoporeia affinis* Lindstrom ceased when temperatures exceeded 14°C. Diapause in many insects requires certain temperatures for its onset or termination (Corbet, 1962; Müller, 1970), and dormancy in many temperate-zone aquatic macrophytes is strongly influenced by the temperature of the water (Sculthorpe, 1967).

Many organisms that require certain temperatures for the successful completion of various phases of their life cycles have the limits of their zoogeographical distributions outlined both latitudinally and altitudinally by climatic factors related to temperature. Smith (1973) found that breeding by *Gammarus lacustris*

Sars became increasingly unsuccessful at temperatures above 18°C. This finding is compatible with the known geographical distribution of this species, both in North America (Bousfield, 1958), and in northern Europe (Hynes, 1955).

It may, at times, be possible to predict responses that a given species will exhibit to an altered thermal environment from information on its distribution, and from the timing of events within its life cycle. It cannot, however, be expected that a whole community or ecosystem would produce a response that would be equivalent to the sum of the responses that each species would have shown independently. Often certain species, or groups of species, exert so strong an influence on others that the response of a whole community to a perturbation ultimately depends on the manner in which a few species respond. Therefore, when dealing with altered communities, it should be expected that a great many of the observed changes, in species composition and in relative dominance among species, will be of an indirect nature.

The literature on responses of macroinvertebrates to increased environmental temperatures is meagre, and no studies concerning whole communities have been done. Generalizing concepts in this area have been slow to emerge and difficult to test due to variability in the induced temperature regimes, the diverse manners of entrainment and discharge of heated waters, and the inherent variability of the biotic and abiotic aspects of ecosystems receiving thermal discharges.

Limited knowledge of the systematics of macroinvertebrates, such as chironomid larvae, makes studies of whole, freshwater animal communities difficult to carry out.

Several studies concerning the effects of thermal effluent on macroinvertebrates pertain to man-made reservoirs or impoundments. These studies are concerned with profundal bethic assemblages dominated largely by benthic chironomid larvae and tubificid oligochaetes. Increased numbers of tubificids, especially *Limnodrilus hoffmeisteri* Claparède, together with reduced number of chironomid species, were observed in heated regions of reservoirs by Koss *et al.* (1974) and by Brinkhurst and Jamieson (1971). Also, Whitehouse (1971) and Koss *et al.* (1974) found that some of the heated portions of the reservoirs that they studied, supported very large populations of *Chironomus* larvae.

Craven and Brown (1970) noted very few effects of a heated discharge to Boomer Lake, a reservoir situated in Oklahoma, U.S.A. The temperature differential induced by the small (21.75 MW) generator was on the average less than 0.5°C at the substrate level. Though it was not pointed out in their paper, the tabulated data presented indicated that *Branchiura sowerbyi* Beddard may have spawned earlier at the station near the heated discharge. Brinkhurst and Jamieson (1971) noted that *B. sowergyi*, although endemic to tropical latitudes, is often associated with heated discharges at latitudes as far north as Sweden and Great Britain (Brinkhurst, 1966; Mann, 1958, 1965).

Studies of artificial lakes cannot reveal the full spectrum of interactions between faunal assemblages and thermal discharges due to the low faunal diversity characteristic of such systems. Trichoptera, Odonata, Ephemeroptera, Amphipoda, Gastropoda, Hirudinea and littoral species of Chironomidae are extremely important components of the fauna of lacustrine systems and are seriously under-represented in such man-made water bodies. The extensive fluctuations in water levels, which are characteristic of reservoirs, tend to preclude the development of stable, littoral communities.

Nuclear power stations on the shore of Lake Ontario release heated water to a littoral community. Storr and Schlenker (1974) reported large numbers of perch (*Perca flavescens* Mitchill and *Roccus ammericanus* Gmelin = *Morone americana*) in the heated zones at all times of the year, and they attributed this to the high concentrations of *Gammarus* spp. that occurred within the heated areas. *Gammarus pseudolimnaeus* Bousfield and *G. fasciatus* Say are both abundant in the Great Lakes (Bousfield, 1958), but the information on temperature preferences given by Bousfield indicates that the species, referred to by Storr and Schlenker (1974), is likely *G. fasciatus*. Gallup, Hickman, and Rasmussen (1975) showed that in thermally affected littoral areas of Lake Wabamun, Alberta, high numbers of molluscs and tubificid oligochaetes formed the bulk of the macroinvertebrate fauna, whereas amphipods and chironomids were dominant in less affected littoral regions. Sankurathri and Holmes (1976a) showed that *Physa gyrina* Say, a littoral gastropod, occurred in abnormally high densities near the heated water discharge from the Wabamun power station. Agersborg (1932) also found *P. gyrina* in great numbers in areas affected by warm waste waters.

All of the foregoing results were obtained from areas where temperature differentials at the substrate level were from 0.5°C to 10°C under the temperature regimes induced by the thermal effluents. Howell and Gentry (1974) reported data on streams of the Savannah River system near Aiken, S.C., which receive thermal effluent from nuclear production reactors. Summer temperatures reported from the Four Mile Creek study site exceeded 40°C (Howell and Gentry, 1974). Here, only 22 species of macroinvertebrates could be collected, and 96% of the individuals collected belonged to two species, a corixid and a large *Chironomus* species. Winter temperatures at this area were from 30°C to 33°C. Some stretches of the creek near the outlets had temperatures exceeding 50°C wherein only thermophilic bacteria could be found. The temperatures reported by Howell and Gentry are the highest temperatures reported so far in any literature on thermal effluents.

Besides the direct effect of temperature elevation on the creek fauna, Howell and Gentry (1974) also documented destruction of most of the shoreline vegetation, which resulted in destabilization of the banks and extensive siltation. The light regime was also considerably altered due to the elimination of much of the forest canopy.

A stream that had previously suffered much the same type of damage as Four Mile Creek, but whose thermal input had been terminated 5 years previous to the study (Howell and Gentry, 1974), yielded 45 species of aquatic insects with a predominance of chironomids. The shoreline vegetation was gradually becoming re-established, but the residual silt probably accounted for the predominance of chironomids in the fauna. Howell and Gentry (1974) also described the results of collections from Upper Three Runs Creek, an unaltered stream nearby. This stream yielded 54 species from a collection only half of the size of those made at the previously described locations. In Upper Three Runs Creek the Plecoptera, Trichoptera, and Odonata were quite abundant, and all orders of macroinvertebrate animals were more evenly represented.

Wiederholm (1971) described the effects of heated discharges into Vasteras Bay of Lake Malaren, Sweden. This bay also receives large inputs of organic pollution from sewage outlets, and is markedly affected by nearby urban centers. His results pertain to the profundal benthos and little mention is made of littoral fauna. The tubificid oligochaetes, *B. sowerbyi* and *L. hoffmeisteri*, were the most abundant benthic invertebrates recorded in the area affected by the thermal discharges. Chironomids were more abundant at points further from the discharges. As the thermal inputs were stepped up in 1969, these trends were amplified. Tanytarsini (Chironominae, Chironomidae) were not common within the polluted bay, but *Chironomus plumosus* (L.) was fairly abundant in this region at depths around 4 m. Tanytarsini were more abundant at similar depths in unaffected regions.

The relationship between the manner in which thermal effluents are entrained and released, and the resulting responses of macroinvertebrates, has received no attention thus far. Since such factors as the current resulting from the discharges, the depth of discharge canals, and turbulence within the plume areas markedly affect such processes as periphyton production (Coutant, 1970), it seems likely that faunal elements would also be influenced.

In general, the literature reviewed indicates that mild to marked reduction in the numbers of taxa occurs in areas affected by heated effluent, and that the extent to which such reductions in diversity have occurred appears to be more or less dependent on the temperature differentials established. Most of the studies indicate that shifts in relative dominance have occurred within the affected communities, and that certain ordinarily less abundant species (usually tubificid oligochaetes) flourish under the altered conditions. The mechanism with which a given species is eliminated from a heated region is a matter of considerable ecological and physiological interest. Of significant interest also is the manner in which the life history or behavior of a species, surviving in a heated area, is altered in response to the altered temperature regime. This may in certain cases provide insights relating to the mechanism through which other species have been eliminated.

Barnett and Hardy (1969) have pointed out that some species of intertidal invertebrates undergo noticeable shifts in the timing of their life history patterns in regions affected by heated discharges. The gastropod *Nassarius reticulatus*, the amphipod *Urothoe brevicornis*, and the harpacticoid copepod *Asellopsis intermedia* initiated breeding several weeks to two months earlier at the heated sites than in areas where temperature regimes were normal. Barnett and Hardy (1969) carried out their investigation at the discharge site of the Hunterston generating station on the Scottish coast, and the temperature differentials involved were around 5°C. Sankurathri and Holmes (1976a) noted that spawning in *Physa gyrina*, a freshwater pulmonate snail, occurred the year-around in the vicinity of the heated discharge from the Wabamun power station on Lake Wabamun. In areas not affected by the discharges, the species spawned only in mid-summer. Sankurathri and Holmes (1976b) also noted that the relationship of *P. gyrina* to its external commensals (*Chaetogaster* spp.) and its parasitic trematodes was significantly altered in the heated area during the summer months. When temperatures reached 25°C, the commensals abandoned the snails and the incidence of the trematode infections rose markedly. Agersborg (1932) also recorded year-around spawning in *P. gyrina* in an area receiving discharges of heated waters.

Sawyer (1974) noted that heated effluents accelerate the onset of spawning in many species of leeches. It appears characteristic of these animals to respond in this fashion since it has long been known that in rivers displaying altitudinal temperature gradients, the eurythermal species of leeches breed weeks earlier in the warmer reaches (Sawyer, 1974).

Earlier emergence of aquatic insect populations occupying warmer areas has been noted by Radford and Hartland-Rowe (1971). Several species of stoneflies emerged earlier in streams of the north-western United States than in the streams of Alberta and British Columbia. Nebeker (1971a) observed that in a Utah stream emergence commenced in January for some species in the lower reaches, and that the same species emerged from 4 to 6 months later in the upper reaches. Nebeker (1971b) was able to obtain similar results under laboratory conditions using controlled temperature cultures. These results indicate that in areas affected by heated effluents the emergence patterns of the aquatic insect species might be markedly out of phase with those found under normal temperature conditions. Consequently, many species may find air temperatures grossly inhospitable at the times they emerge from heated regions. It would appear that even slight temperature differentials could be responsible for such effects. Coutant (1967) demonstrated that a 1°C temperature differential downstream from a thermal discharge resulted in emergence of hydropsychid caddisflies two weeks in advance of the emergence from upstream localities.

Although most of the research on the responses of biota to increased temperatures has been of an empirical nature, some theoretical models have been put forward recently. A general and simple model relating the response of a community to a thermal input was advanced by Odum and Kroodsma (1976). They hypothesize that community productivity is enhanced by the thermal energy up to a certain point, beyond which it declines with intensified thermal input. Simultaneously, the community diversity is hypothesized to show either an initial slight increase or a slight decline until temperature differentials reach an intensity sufficient to initiate the productivity decline. Subsequently, the diversity parameter declines along with the productivity parameter as temperature differentials are further amplified. Odum and Kroodsma (1976) refer to that point, where both community parameters begin to decline, as the "stress point" of the system. Although no detailed framework was proposed for the mechanism of interaction between the community productivity and the community diversity, this model could be at least descriptively accurate for many situations.

Cairns (1976) has also advanced some abstract concepts relating to the responses of whole ecosystems to thermal stresses. Most of these are strongly management-oriented and founded on stability criteria applied in engineering sciences. He proposes such state parameters as "ecosystem vulnerability", "elasticity", and "resiliency" to be assessable parameters which would allow more effective site evaluations, control and management.

Gibbons (1976) has elaborated a "thermal enhancement" model and has reviewed some of the literature documenting cases that support his theory. He argues that, since nature has eliminated genetic sets which are not capable of adjustment to some degree of thermal fluctuation, most species are then capable of withstanding at least slight increases in the average temperature of their environments. Gibbons (1976) then argues that, until temperatures deleterious to the species have been reached, the energy increment will cause an increase in the parameter that he calls "population success". Beyond this point, further increases in temperature would then adversely affect the population success. Gibbons does not deal with a major implication that his theory suggests. If most species stand to benefit from slight to moderate increases in their environmental temperature, the implication is that they are optimally adapted to live at temperatures higher than those under which they are normally found. It seems, however, conceivable that a good proportion of the species inhabiting a given locality might already be living at, or even above, their optimum temperatures. For such species, it certainly does not follow that slight increases in the temperatures of their environments would result in enhanced success.

The study of the effects of temperature elevation on ecological communities required knowledge of the species composition of both altered and unaltered communities. In Lake Wabamun, a considerable diversity of littoral habitat conditions is present, and this presented an opportunity to study the manner in which different habitat variables (i.e. substrate type, amount of macrophyte growth, amount of plant debris within the sediment, *et cetera*) affect the species composition of macroinvertebrate communities. Information of this type is necessary to allow initial hypotheses to be formulated concerning the mechanism involved in community alterations associated with increased temperatures.

This study of macroinvertebrate communities of Lake Wabamun was therefore carried out with the following objectives at the forefront. The first was to identify, or at least become acquainted with, as many of the species present within the study area as possible. The second was to examine, over the course of at least 1 full year, the species composition of macroinvertebrate communities in as many habitats as possible Early in this study, an extensive series of transects were sampled, and on the basis of the information acquired, 19 stations were selected for regular sampling. Data on the species composition of the macroinvertebrate fauna were collected, over at least one complete annual cycle, at each of these stations. Samples from these transects contributed much basic information on the patterns of change in species composition with respect to depth, the nature of the substrate, and other habitat variables.

These studies were combined with year-around measurements of temperature at 14 of the stations. Temperature studies were done in order to compare the thermal regimes of the stations, and to obtain a better knowledge of the seasonal pattern of change in the thermal regime of the deepest portions of the lake.

Temperature regimes in Lake Wabamun and the influences of heated discharges from the power stations were described by Gallup and Hickman (1973, 1975), and Klarer, Hickman and Gallup (1973). Photographs and figures, outlining the extent of areas kept ice-free during winter by the effluents, have been presented in the above papers and in the works of Allen (1973), Ash (1974), and Noton (1974). Nursall and Gallup (1971) outlined the thermal plume in the surface waters of Kapasiwin Bay and showed the degree to which it is altered by winds from various directions. Nuttall (1974) presented data outlining the thermal plumes in the surface waters of Kapasiwin Bay and Indian Bay. Temperature profiles showing the extent of vertical mixing within the plumes were also presented by Nuttall (1974).

Lake Wabamun is shallow, and much of its area is littoral in character. This, together with the fact that the power stations released their heated waters into littoral bays, makes Lake Wabamun an ideal location for a study of littoral and sublittoral biota. It is known that heated effluents from the power stations at Lake Wabamun have affected certain components of the lake's flora and fauna (Nursall and Gallup, 1971), and that the most notable of the observed effects are those pertaining to the enhanced macrophyte growth recorded in littoral areas receiving heated effluents (Allen, 1973; Allen and Gorham, 1973).

The influence of heated discharges on macrophyte growth should result in differences between the benthic communities found near the discharges and those found at distant stations. The relationship between the chironomid assemblages of profundal sediments and the amount of decaying organic material within them has been well established (Thienemann, 1925, 1928; Lundbeck, 1926, 1936; Brundin, 1951). The carry-over of this relationship into littoral regions is well known (Thienemann, 1954; Saether, 1975), despite the paucity of knowledge concerning a great many of the species present in shallow waters. From what is known, it could be hypothesized that sediments rich in decaying plant material and characterized by a high oxygen demand should support an eutrophic benthic chrionomid assemblage characterized by a high standing crop and dominated by large *Chironomus* species. On the other hand, sediments receiving little decaying macrophyte material should feature lower standing crops and dominance by other chironomid species.

Most of the macroinvertebrates found upon vegetation during the growing season must overwinter upon fallen plant remains or within the sediment itself, where oxygen is not nearly as plentiful as it is around erect plants. It could therefore by hypothesized that areas near thermal discharges, featuring excessive amounts of macrophyte vegetation, might have different weed-dwelling macroinvertebrate communities than areas with less macrophyte vegetation. Larvae of the Orthocladiinae are generally a strong component of the weed-dwelling animal community (Thienemann, 1954), and these larvae are also among the most sensitive of animal species to oxygen deficiency (Brundin, 1951; Thienemann, 1954). Hence, one might suggest that this group in particular could exhibit such differences.

For these reasons, it was considered an important goal of this study to examine the macroinvertebrate assemblages in areas supporting various amounts of macrophyte growth and macrophyte accumulation. This would then allow assessment of the impact of enhanced macrophyte growth on macroinvertebrate assemblages, effects which could then be treated as indirect consequences of the presence of heated discharges. Studies were carried out in the area of the discharge from the Wabamun power station both before and during a mechanical macrophyte harvesting program which was aimed at restoration of areas exhibiting excessive macrophyte growth. Macrophyte harvesting resulted in a marked reduction in the amount of plant matter which accumulated within the sediment. It was, therefore, possible to assess the relative importance of the temperature factor and the macrophyte accumulation in determining the composition of the animal communities of the heated areas.

LAKE WABAMUN

I. A REVIEW OF ITS PHYSICAL, CHEMICAL AND GEOLOGICAL FEATURES

Lake Wabamun is situated 64 km west of Edmonton, Alberta. The latitude, longitude and morphometric data have been published by Nursall and Gallup (1971), Gallup and Hickman (1975) and Schwartz and Gallup (1978). Figure 1 illustrates the lake and gives depth contours, substrate morphometry, locations of the power stations, and locations of the sampling stations used in this study. The long axis of the lake is aligned approximately east-west, and consequently, the lake presents a considerable fetch for storm-force winds, which usually blow from the west. The effect of storms can be seen from the presence of gravel beaches on all exposed, windward shores (Fig. 1). The shoreline of the lake is relatively uncomplicated (shoreline development, 1.81).

Lake Wabamun is far from uniform with regard to its basin morphometry, shoreline features and sediment characteristics. The western two-thirds of the lake has approximately the character of an elongate trough, with its point of maximum depth (11.5 m) near the west end. This portion of the lake is made up predominantly of 6-10 meter deep basin areas, bordered by sharp drop-offs from beaches of sand or gravel. The occurrence of soft ooze substrate in shallow areas of the western portion of the lake is much less common than it is in the eastern portion. In the eastern portion of the lake, the shoreline is more complex, drop-offs are more gradual, and large littoral bays are present. Hard clay or gravel substrate can be found along shores exposed to strong wave action, but most of the shallow area is fairly well protected and features soft mud substrate,

Figure 1. Map of Lake Wabamun.

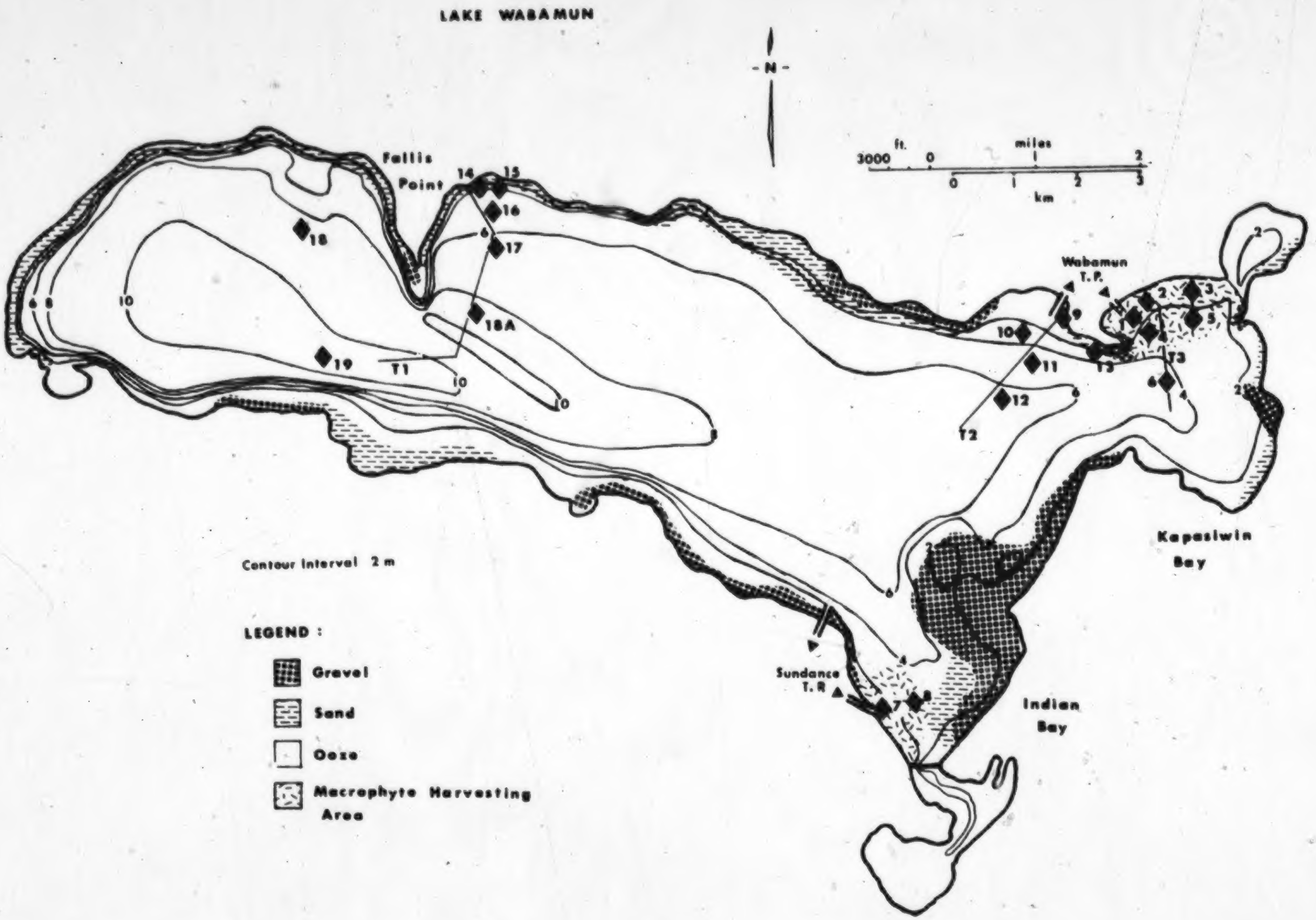
Depth contours (2 m depth intervals), substrate morphometry, location of macrophyte harvesting plots and locations of Stations 1-19, and Transects 1-3 are shown.

T_1 Fallis Transect

T_2 Wabamun Inlet Transect

T_3 Kapasiwin Bay Transect

The power stations are shown and the locations of their water intake and discharge canals are depicted as they were during the study period (prior to October, 1975).


LAKE WABAMUN
-N-
3000 ft. 0 miles 1 2
0 1 km 2 3
Fallis Point
14
15
16
17
18
18A
19
T1
T2
T3
Wabamun T.P.
Sundance T.R
Kapasiwin Bay
Indian Bay
Contour Interval 2 m
LEGEND :
Gravel
Sand
Ooze
Macrophyte Harvesting Area

that supports considerable growth of aquatic plants. Sand beaches are much less common in the eastern portion of the lake than in the western portion.

This east-west morphometric differential can be viewed in relation to the topography and relief pattern of the catchment area. The valley is very steep along the north shore of the lake, with uplands extending more than 65 m above the lake, and reaching their topographical high within 1-2 km of the lakeshore. To the southwest, uplands reach an altitude of about 50-60 m above the lake level, but there is no steep scarp, and the topographical high occurs about 5-7 km from the lakeshore. To the east and southeast (adjacent to the shallow end of the lake), the relief is almost non-existent. The maximum altitude above lake level reached in this direction is no more than about 7 m. The catchment area for the lake was calculated to be 268 km^2.

The depression within which Lake Wabamun is situated is a bedrock channel called the Beverly Valley by Carlson (1966, 1971). This valley is one of the longest preglacial drainage channels known in central Alberta. It extends from the McLeod River valley near Edson, through Chip Lake, is crossed by the present-day Pembina River valley near Evansburg, continues on to Lake Wabamun, and southeastward to its junction with the Drayton Valley (Carlson, 1971). From this point, it courses northeastward toward Big Lake, where it joins the Onoway Valley and receives the Sturgeon River. It then runs eastward north of the city of Edmonton as the Sturgeon River valley until it meets the valley of the present-day North Saskatchewan River near Fort Saskatchewan. The description given by Carlson (1966) of the bedrock topography of the Beverly Valley shows that the section exposed at Lake Wabamun is a very typical one. Carlson writes that the depth of the valley is 200-300 ft (about 60-90 m), with its north wall being fairly steep, and its southern face sloping very gradually. The valley is generally about eight miles wide.

The thickness of surficial deposits within the bedrock channel is extremely variable (see Carlson, 1971). Where they are thin (less than 50 ft. or about 15 m), surficial topography is determined very strongly by the topography of the underlying bedrock. This is the case along the north and southwest shores of Lake Wabamun where sandstone and coal-bearing shale outcrop in many places. In areas where the surficial deposits are thick, the contours of the valley are often obscured by the recent topography, and the modern drainage patterns bear little or no relationship to their preglacial counterparts. This is the case west of Lake Wabamun where the Pembina River crosses the Beverly Valley (surficial deposits 50-150 ft. (about 15-45 m) thick), and also, to the east of Lake Wabamun where the valley is dammed by 150-300 ft. (about 45-90 m) of till until its junction with the Onoway Valley. Consequently, downstream from Lake Wabamun the valley is completely buried and not reflected at all in the present-day topography.

The slope of the land in the vicinity of Lake Wabamun is toward the southeast, in the direction of the North Saskatchewan River. This contrasts with the general slope of land in central Alberta, which is toward the northeast. Lake Wabamun receives no riverine inputs of any consequence, and for the most part, the basin is closed since the surface outflow through Wabamun Creek is negligible except when water levels are extremely high. Even under conditions of high water, outflow via the creek is retarded by a weir. Wabamun Creek leaves the lake from the south shore of Kapasiwin Bay and meanders eastward and southward, through a low-relief area of muskeg, and then descends in a southerly direction to the North Saskatchewan River.

The geological features of the area surrounding Lake Wabamun have been studied by several investigators. Bedrock geology was first described and mapped by Rutherford (1928), and surficial features, including glacial tills, lacustrine deposits, and soils, were surveyed and mapped by Lindsay *et al.* (1968). Two bedrock formations lie near the ground surface in the vicinity of Lake Wabamun, and exposures of both types of rock can be found along the valley slopes. Alongside the western half of the lake, the rocks of the Paskapoo Formation lie uppermost, and are well represented by the sandstone cliffs which form a prominant scarp along the north shore from Fallis Point westward. Paskapoo rocks also form the uplands to the south, along the western half ot the lake (Lindsay, *et al.*, 1968). The Paskapoo Formation is a non-marine deposit of predominantly sandstone and sandy shale of Tertiary age (Allan and Sanderson, 1945). It is the uppermost bedrock formation throughout most of west-central Alberta, east of the foothills. Green (1972) drew its eastern boundary through Lake Wabamun. Throughout most of west-central Alberta, the Edmonton Formation underlies the Paskapoo rocks, but along the uplands to the north of the lake, from about Fallis point eastward, this formation lies close to the ground surface. The Edmonton Formation also underlies the low-relief surficial deposits to the east and southeast of the lake, but in these regions, with the exception of a few patches, the bedrock contours are only slightly above the lake level (Carlson, 1971) at their highest point. The rocks belonging to the Edmonton Formation are of late Cretaceous age, and they are composed mainly of bentonitic shale (Rutherford, 1928); coal seams are very prominent in the upper strata (Pearson, 1959).

The east-west geological transition is also strongly represented in the distribution of surficial deposits (Lindsay *et al.*, 1968). The main surficial feature to the north, west, and southwest of Lake Wabamun is ground moraine. It features a thin mantle of lodgement till, forming a gently rolling plain which often bears fluting features, indicative of active ice-flow. To the north of the lake, the till laid down is of Edmonton Formation origin, and the soils formed from it are predominantly of the Cooking Lake-type (Lindsay *et al.*, 1968). Cooking Lake soils also dominate to the west of the lake, but in this region Lindsay *et al.* indicate that soil of the Modeste-type (originating from Paskapoo rock) is also represented. The Modeste soils are very prominent along the southwest shore of the lake. The dominant surficial feature to the southeast and east of the lake is glacial lacustrine sediment; soils of the Highvale-type are formed from this material and constitute the predominant soil type in this region. The lacustrine materials can be traced southward all the way to the North Saskatchewan River valley, which throughout most of its length from the Rocky Mountain House area to Edmonton, is flanked by a considerable expanse of proglacial lake sediments (Lindsay *et al.*, 1968; Boydell, Bayrock and Reimchen, 1974). The lacustrine sediment east of Lake Wabamun is underlain by thick till deposits that completely fill the Beverly Valley at this point. Much of this till is ablation drift, that was deposited as hummocky moraine by stagnant glacier ice disintegrating in an uncontrolled manner (Gravenor and Kupsch, 1959; Flint, 1971). The predominance of hummocky moraine on the western Canadian plain is considered evidence that ice retreat from the area occurred mainly through stagnation (Gravenor and Bayrock, 1961; Bayrock and Hughes, 1962).

The pattern of till deposits, and its relationship to bedrock topography indicates that damming of the valley with glacial drift was an important factor in the origin of the Lake Wabamun basin. The occurrence of preglacial sands and gravels along the Beverly Valley slopes and their absence from the deepest portion of the valley, suggest that the valley has been considerably over-deepened by glacial acitivity (Carlson, 1966). This process may have contributed to the formation of the Lake Wabamun basin, and possibly also, to the steeping of its relief. The presence of extensive deposits of glacial lake sediment around the southern and eastern portions of the lake indicates that, during the retreat of the Wisconsin continental glacier, the lake was part of a proglacial lake formed by the damming of the North Saskatchewan River by the retreating ice. Recent lake sediments, exposed by declining water levels are not extensive around the margin of Lake Wabamun. This is an indication that the productivity of the aquifers supplying the lake is not declining.

The hydrogeology of the Lake Wabamun area has been studied by Ozoray (1972) and Schwartz and Gallup (1978). The most productive aquifers are the soft, permeable, high relief sandstones (Paskapoo Formation) represented to the northwest of the lake, and localized zones of fractured shale (Edmonton Formation) north of the lake.

Shaley bedrock, that surrounds most of the lake, and glacial lacustrine deposits are moderately productive, but glacial till, due to its unsorted nature and low permeability, is considered very poor aquifer material. The bedrock aquifers are of two types, local or shallow systems, and deep-flow systems (sometimes present beneath preglacial valleys) (Ozoray, 1972). The shallow bedrock aquifers of high productivity feature low TDS (less than 500 mgl^{-1}) Calcium-Magnesium bicarbonate water. The deeper bedrock aquifers (depth greater than 200-300 ft. (about 60-90 m) in recharge areas) have higher salt concentrations and are dominated by Sodium-Magnesium bicarbonate. The chemical character of the water from Lake Wabamun (Schwartz and Gallup, 1978) agrees well with that of the shallow or local-flow bedrock aquifers, suggesting that deep-flow systems are of no direct significance in recharging the lake (Ozoray, 1972). Schwartz and Gallup (1978) found the chemical character of lakewater to be very different from that of local runoff water, and also from that of ground-water obtained from till.

Studies on the history of Lake Wabamun involving the analysis of sediment cores have been done by Fritz and Krouse (1973) and Green (pers. comm.). Fritz and Krouse (1973) analyzed the carbonates from mollusc and ostracod shells taken from cores 10 m deep into the sediments of Lake Wabamun for ^{18}O and deuterium. The values obtained indicated that an evaporative regime had been in existence for over 12,000 years and that throughout the post-glacial interval, the intensity of the evaporative process had fluctuated in response to climatic changes. There was, however, no evidence of gross alterations in the relative amount of evaporation throughout the period. Ostracod shells from these cores were identified by R.D. Green, who found that the species composition indicated a short proglacial lacustrine phase, followed by a long interval throughout which the community was very similar to that presently occurring in the lake (R.D. Green, pers. comm.).

Fritz and Krouse (1973) indicated that the content of ^2H_2O and ^{18}O in the water of Lake Wabamun was significantly below that of a series of ponds which were very high in TDS, and that this, together with the low values of TDS in the lakewater, indicated that evaporation was by no means the major avenue of water loss from the basin. Potential evapotranspiration in the area exceeds precipitation by almost 10 inches (about 25 cm) per year (Ozoray, 1972). Schwartz and Gallup (1978) also felt that the low concentrations of ions such as chloride and sulfate present in the lakewater indicated that evaporation was not producing a significant concentrating effect. Fritz and Krouse (1973) also reported the occurrence of high ^2H_2O and ^{18}O in the water from wells in the lower reaches of the Beverly Valley. These observations indicate that underground flow through the lake basin is probably very significant. The presence of very permeable sediments (sand and gravel) throughout most littoral areas of the lake indicates that sub-surface seepage from the periphery of the basin is probably occurring; the thick layer of very fine sediments capping the bottom of the basin precludes either groundwater inflow or seepage out from the central portions of the basin. The surficial outflow, which occurs intermittently through Wabamun Creek, is certainly not sufficient to prevent evaporative concentration of salts. Underground seepage from lake basins can buffer against nutrient enrichment both through evaporation and through loading of nutrients into the lake.

The presence of high permeability aquifers around the shores of Lake Wabamun, coupled with the capacity for seepage from the lake basin, makes Lake Wabamun a high discharge area whose watershed is integrated into the overall drainage pattern of the area. Under such conditions water levels remain stable and salts of high solubility (Sodium and Magnesium sulfate) do not accumulate in the lake. The importance of leaching of sulfate salts from a watershed should not be underestimated. Sulfate, by supporting the growth of sulfate-reducing bacteria, which produce sulfide, can hinder or abolish the ability of the sediment to accumulate phosphate. Lakes situated on hummocky moraine east of Edmonton can be compared, in this regard, to Lake Wabamun. The basins are mainly moraine plateaux and kettles (Gravenor and Kupsch, 1959) that are seated in ablation till that is so impermeable that the rate of groundwater supply is insufficient to offset evapotranspiration in the discharge areas. Although relief is fairly high, the hummocky terrain plus the impermeability of the till prevents establishment of integrated drainage systems (Pawluk and Bayrock, 1969). Under these conditions, the highly soluble salt, Sodium sulfate, leached from the uplands, accumulates in discharge areas. Values of sulfate recorded in such lakes are 20-100 times as high as those of Lake Wabamun, and values of total phosphate are 5-25 times as high as those recorded for Lake Wabamun (Gallup, Weisgerber and Rasmussen, 1977; Gallup and Rasmussen unpublished data.)

II. A REVIEW OF THE BIOTIC FEATURES OF LAKE WABAMUN

Wheelock (1969) characterized the phytoplankton community of Lake Wabamun as an eutrophic assemblage dominated by diatoms and some Chlorococcalean species. Rather than producing blooms of *Anabaena* species, *Microcystis aeruginosa* Kutzing, and *Aphanizomenon flos-aquae* (L.), as is the character of many of the nearby lakes and ponds, Lake Wabamun has an extraordinarily diverse assemblage of myxophycean species. None of these were observed in bloom quantities by either Wheelock (1969) or Noton (1974).

Noton (1973, 1974) described the seasonal pattern of primary productivity in Lake Wabamun. At all of the stations that he studied, most of the annual production occurred within two peak periods. The first occurred in early spring as the waters were warming, and the second and larger peak occurred during late August and September. When this pattern is compared to the seasonal succession of the phytoplankton, it is evident that the peaks essentially conform with diatom pulses.

Epipelic algal communities were found by Hickman (1974) to be dominated by diatom species, except where heated effluents were strongly affecting the populations. The seasonal periodicity of the standing crops of epipelic and epipsammic algae were studied at several stations. At the deep water station (4.0 m), peak standing crops were recorded in early June and late October, and the intervening midsummer to early autumn standing crops were consistently low. Moderate standing crops were observed under ice cover. The peaks recorded by Hickman (1974) occurred about three weeks later in the season than those recorded by Noton (1974). It is possible that some of the nutrients released, when phytoplankton cells accumulate and die at the sediment-water interface, contribute to the growth of epipelic algae.

Hickman found that the shallow littoral stations supported high, but erratically fluctuating, populations of epibenthic algae throughout the ice-free season. He attributed these fluctuations to overturn of the sediments caused by storms. Hickman (1974) also found that standing crops of epipsammic algae, which grow on the sandy beaches, were about an order of magnitude higher than standing crops of epipelic algae from muddy littoral substrates.

A fairly diverse array of aquatic plant species was reported for the lake by Allen (1973). These included 26 species of submerged and floating-leafed plants and 7 species of emergent plants. Allen (1973) also mapped the distributions of the most prominent assemblages within the lake basin. The most widespread community was an association of low growing *Chara globularis* Thuill. with *Potamogeton vaginatus* Turca., which was observed to grow on sand and gravel sediments, and was the dominant community in the western two-thirds of the lake. The community that occurred most frequently in the soft-bottomed littoral regions of the eastern portion of the lake was referred to as a mixed *Myriophyllum exalbescens* Fernald, *Chara globularis* assemblage. *Ceratophyllum demersum* L., *Potamogeton richardsonii* A. Benn., and *P. vaginatus* were commonly noted within this community. Stanley and Dobson (1961) found this assemblage to be characteristic of the littoral regions of Kapasiwin Bay, and Allen (1973) indicated that this assemblage was present on the southwest side of Indian Bay prior to the commencement of thermal input to that area. *Elodea canadensis* (Michx.) was noted by Allen (1973) and Haag and Gorham (1977) as an extremely common species in the eastern portion of the lake and these authors have related the presence of this species to the presence of extensive areas where thermal discharges prevent the formation of winter ice. Early reports on the vegetation of the lake by Stanley and Dobson (1961) and Allan (1954) did not mention the presence of this species.

Although the animal communities of Lake Wabamun have not been described as completely as the plant communities, some studies have been performed and the species composition of the zooplankton and the fish communities is fairly well known. Horkan (1971) recorded 47 species of rotifers which included a characteristically eutrophic assemblage of species together with many species that occurred in and around stands of aquatic macrophytes. Nursall and Gallup (1971) listed planktonic crustaceans found within the lake, but their list does not include many species found in littoral areas near and upon aquatic vegetation. Gallup, Rasmussen and Hickman (1973) recorded the presence of *Chironomus* spp., *Chaoborus* sp., *Procladius* spp., *Tanytarsus* spp., *Limnodrilus hoffmeisteri* and *Tubifex* spp. within sediments of littoral and sublittoral regions of the eastern portion of the lake. This assemblage would suggest a state of moderate to strong eutrophy after the criteria outlined by Saether (1975).

Eight species of fishes were reported to occur in the lake by Nursall and Gallup (1971). Ash (1974) reported on food habits, spawning grounds and other aspects of the biology of the lake whitefish, *Coregonus clupeaformis* (Mitchill). Northern pike, *Esox lucius* Linnaeus, yellow perch, *Perca flavescens* (Mitchill), and spottail shiners, *Notropis hudsonius* (Clinton) are the other numerically abundant species of fish in Lake Wabamun, but nothing has yet been written on the life history, feeding habits or spawning, *et cetera* of these species in this lake.

III. A REVIEW OF THE HISTORY AND IMPACT OF THERMAL INPUTS TO LAKE WABAMUN

The proximity and extensiveness of coal seasm to the north and south of the lake, and their accessibility to surface mining operations have made Lake Wabamun an ideal situation for the establishment of coal-fired electric power stations. The Wabamun station is located north of Kapasiwin Bay (Fig. 1) and was commissioned in 1956. The first unit was rated at 75 MW, but during the 1960's three more units were added bringing the total power output to 582 MW (Crosby-Diewold and Krochak, 1975). The Sundance station is situated on the western shore of Indian Bay and began to operate in 1970 with one unit producing 300 MW. Subsequently a second 300 MW unit was added, and 6 more units are planned (Crosby-Diewold and Krochak, 1975). Both stations drew cooling water for their condensers from the lake, and until 1975 both released their heated discharges into the lake via discharge canals. At that time, a cooling pond was constructed to the south of Indian Bay, which presently receives the discharges and provides the cooling water to the Sundance station. All of the thermal effluent from the Wabamun station is still being released into Kapasiwin Bay.

Nursall and Gallup (1971), Allen (1973), Allen and Gorham (1973), and Gallup and Hickman (1975) gave information on circulation rates, temperature differentials, and the nature and extent of the thermal plumes produced by thermal effluents. The year-around inputs of heated water resulted in several hundred acres of ice-free area within the heated bays during winter months. The extent and outline of these areas were depicted by Allen (1973), Ash (1974), and Noton (1974). Early ice-melt occurs in most areas of the eastern portion of the lake.

Since the power stations were established, many effects on the biota of the lake have been observed and documented. Allen (1973) noted that the species composition of the macrophyte community near the Wabamun discharge had been radically altered from that discribed by Stanley and Dobson (1961) and Allan (1954). Around the mouth of the discharge canal, the *Myriophyllum - Chara* community had been replaced by a pure stand of *Potamogeton pectinatus* L., and within the heated regions, *Elodea canadensis* had become the dominant species. *Elodea* had first been noted by Wheelock (1969), and in a relatively short time it reached nuisance proportions within Kapasiwin Bay. This species has a pronounced tendency to break free of the substrate and form rafts during storms. The accumulation of rafts of vegetation on beaches prompted concern from local residents (Nursall and Gallup, 1971). In 1972 Calgary Power Ltd. initiated a program of mechanical macrophyte harvesting in Kapasiwin Bay in an effort to alleviate the situation (Gallup, Hickman and Rasmussen, 1975).

Allen (1973) observed stages of a very similar species replacement on the southwest side of Indian Bay in the interval from 1970 to 1972. He observed that the newly excavated Sundance discharge canal was rapidly colonized by *Elodea*, *P. pectinatus*, and *Myriophyllum* and that over the first year after initiation of thermal discharge, *P. pectinatus* gradually replaced the other two species. Vegetative propagules of *Elodea* were, however, being dispersed into the plume area where clumps of the species were becoming established in areas where *Chara* and *Myriophyllum* had died off. From these patches, *Elodea* had spread to an area of 75 acres by 1972 (Allen, 1973).

Haag and Gorham (1977) described the seasonal dynamics, growth, and productivity of macrophytes in the eastern portion of Lake Wabamun. They found that the excessive biomass production by *Elodea* occurred in the area adjacent to the Wabamun heated discharge and that the ability of this species to compete favourably was related to its lack of a low temperature dormancy response. They found that in areas where insolation was not terminated by winter ice cover, *Elodea* continued to assimilate and grow much later in the season than resident species, that initiated a dormancy response at low temperatures. This enabled *Elodea* to accumulate a higher biomass for its winter carry-over, from which it initiated its spring growth before dormancy had been broken in other species. Haag and Gorham (1977) felt that *Elodea* was only marginally adapted for life at these latitudes, since its lack of a true dormancy prevented significant quantities of this species from over-wintering in areas which received 5 months or more of winter ice cover.

Studies by Beak Consulting Ltd. have been carried out from 1975 until the present time. One of the purposes of their studies has been to ascertain whether or not *E. canadensis* was affected by cessation of thermal inputs to the Indian Bay area and the resumption of full winter ice cover in the region formerly affected by the Sundance discharge. Although annual reports on this study are available (Crosby-Diewold and Krochak, 1975, 1976), no conclusions have as yet been reached from the Beak studies.

Other effects of thermal discharges on the lake's biota have been noted. Horkan (1971) described alterations in the seasonal succession and population dynamics of planktonic rotifers in the area of the Wabamun discharge. Some species showed an enhancement of egg production whereas others displayed a reduction or a complete cessation of egg production. Noton (1973, 1974) found that although surface primary productivity was enhanced in heated areas the seasonal patterns were not greatly altered, and no blooms or excessive growths resulted. Wheelock (1969) reported smaller standing crops of phytoplankton in the heated regions than were in evidence in unheated areas and felt that this may have resulted from inhibition by extensive growths of macrophytes in the area receiving thermal effluent. Nursall and Gallup (1971) showed that *Diaptomus oregonensis* Lilljeborg did not achieve as high population densities in the area of the Wabamun outlet as it did at other stations within the lake. They found, however, that *Chydorus sphaericus* (Müller) was more numerous in the heated water than elsewhere.

Klarer and Hickman (1975) compared standing crops of epiphytic algae from the stems of *Scirpus validus* Vahl. from heated and unheated stations. They found that, in the areas of both the Wabamun and the Sundance discharges, the numbers of species present in the communities were less than the numbers recorded at unheated stations. Communities from areas affected by heated discharges were aften dominated by green and blue-green algae rather than by the diatoms characteristic of unheated locations. The spring standing crop maximum occurred much earlier in the season at stations near the discharges. Hickman (1974) also reported that the standing crops of epipelic algae were higher in heated regions and that this differential was mainly a function of the enhanced growth of *Oscillatoria* species.

Ash (1974) did not find marked differences in the size or condition factors of lake whitefish caught in heated areas as compared to those caught in unheated areas. Fish caught in Kapasiwin Bay were noted to be feeding heavily on the tips of *Elodea* plants, which were aften seen floating freely in the water. Whitefish that he examined from the western portion of the lake never fed on plant material. Gallup, Hickman and Rasmussen (1975) and Ash (1974) reported that standing crops of benthic organisms were higher in sublittoral regions near the discharge from the Wabamun station than at a station of the same depth in the western portion of the lake. Gallup *et al.* (1973, 1975) reported that, in the area immediately adjacent to the mouth of the Wabamun discharge, the macroinvertebrate communities were dominated by gastropods and tubificid oligochaetes, whereas chironomid larvae and amphipods were found to be dominant macroinvertebrates at a station farther from the discharge. Folsom (1976) reported much higher populations of *Dugesia tigrina* (Girard), as well as earlier spawning, at a station affected by the Wabamun discharge when compared to a station from the western portion of the lake.

THE STUDY AREA

Figure 1 is a map of Lake Wabamun showing depth contours, substrate types, and locations of stations used for regular or intermittent sampling during this study. The description of each station includes a summary of its major physical and biotic attributes. Thirteen of the 19 stations were located in the eastern portion of the lake. Six of these were located within Kapasiwin Bay, two within Indian Bay and the remaining five in regions of the east end of the lake which appeared to be uninfluenced by heated effluents. Six stations were located in the western portion of the lake, near Fallis.

Sampling stations ranged in depth from 1.5 m to 11.0 m and can be categorized by depth as follows: seven of the stations were 1.5 m deep, five were 2.5 m to 3.0 m deep, three were 4.5 m deep, two were 6.0 m deep, one was 8.0 m deep, and one was 11.0 m deep. The depths used to characterize each of the stations were the depths recorded during May or June of 1973. During the spring of 1974 water levels rose by almost 0.5 m, but over the course of the summer of 1974, and throughout 1975, the levels returned to approximately those of 1973.

I. THE SAMPLING STATIONS OF KAPASIWIN BAY

Kapasiwin Bay consists predominantly of littoral habitat, which supported a rich growth of aquatic macrophytes during all summers of this study. The substrate is predominantly ooze, but a sand beach is located on part of the eastern shoreline. The maximum depth of the bay is approximately 5.0 m. Heated water from the Wabamun power station empties into the northwest portion of this bay.

The ooze found at all of the Kapasiwin Bay stations was very rich in marl, mollusc shells and plant fragments. This was expecially so in 1972 prior to initiation of macrophyte harvesting in Kapasiwin Bay. At that time, screened 15 cm x 15 cm Ekman grabs from stations 1 - 6, from which the living plant material had been removed, occupied from about 400 ml to more than one liter. For comparison, samples from the same stations during 1974 and 1975 occupied from 75 ml to a maximum of about 500 ml. Data on this parameter were not consistently recorded, so it is impossible to calculate the exact magnitude of the reduction in quantity of plant debris within the sediment.

Station 1, located slightly to the east of the mouth of the Wabamun discharge canal, had a depth of 1.5 m and a substrate of soft ooze. Its macrophyte community was always dominated by *P. pectinatus*, but *Myriophyllum*, *P. richardsonii*, and *Elodea* occurred there as well. Some current from the discharge was always detectable at this station.

Station 2 was situated to the northeast of Station 1, on the north shore of Kapasiwin Bay at a depth of 1.5 m. The substrate was ooze and the macrophyte community was dominated by *Myriophyllum*, but *Ceratophyllum*, and *P. richardsonii* were quite common.

Station 3 was located about 1 km to the east of the Wabamun discharge on the northern shore of Kapasiwin Bay. It's depth was also 1.5 m and the substrate was ooze. *Myriophyllum* and *Chara* were the dominant macrophyte species at this station, and *Ceratophyllum* was also commonly encountered.

Station 4 was located about 100 m from the mouth of the Wabamun discharge canal, in a direct line with the flow. The depth of the water was 3.0 m and the substrate was a very black, soft ooze. *Elodea* grew in an almost pure stand at this station during the summer of 1972, but in all subsequent years, this species was found in a mixed assemblage with *P. pectinatus* and *Myriophyllum*. *Oscillatoria* species grew abundantly at this station, both on the substrate and on the vegetation at all times.

Station 5 was located near Station 3, at a depth of 2.5 m. The substrate was ooze and upon it grew *Myriophyllum* and *Elodea* along with some *Ceratophyllum*, *Potamogeton zosteriformis* Fernold, and *P. richardsonii* during the summer months.

Station 6 was located in the center of Kapasiwin Bay. The depth was 4.5 m and the ooze substrate supported only a very sparse growth of *Elodea* during the summer months. Vegetation did, to a certain extent, accumulate upon the substrate following the growing season as it became uprooted from shallower areas and redistributed by water movements.

II. THE SAMPLING STATIONS OF INDIAN BAY

Indian Bay is also predominantly littoral habitat with a soft ooze substrate and a maximum depth of only slightly more than 3.0 m. A beach of mixed sand, gravel and clay is present on its eastern shoreline. During this study heated water from the Sundance power station was being discharged into the western portion of the bay.

Station 7 was situated near the mouth of the Sundance discharge canal at a depth of 1.5 m. The ooze substrate supported a dense macrophyte community composed of *P. pectinatus*, *Myriophyllum*, and *Elodea*. The current from the heated discharge was always detectable at this station.

Station 8 was located farther from the discharge than Station 7, and it was in direct line with the flow of the thermal effluent. The depth was 3.0 m and the bottom was soft ooze. Macrophytes present were *Elodea*, *P. vaginatus*, and *Chara*. Station 8 was located near the center of Indian Bay and its depth was the maximum depth detected within the bay.

III. OTHER STATIONS FROM THE EAST END OF LAKE WABAMUN

The five remaining east-end stations were located in the vicinity of the intake canal for the Wabamun power station.

Station 9 was located in a sheltered area to the northwest of Point Alison, on the shore of the lake near the Wabamun intake canal. Its depth was 1.5 m and the substrate was composed of ooze containing moderate amounts of macrophyte remains, especially the marl coating from *Chara*. At this station a rich diversity of macrophyte species were present. The most abundant species were *Chara*, *Myriophyllum*, *P. zosteriformis*, *P. richardsonii*, *Potamogeton friesii* Rupr., *Najas flexilis* Willd., and *Utricularia* sp.

Station 10 was located slightly to the west of the Wabamun intake canal at a depth of 3.0 m. The substrate was ooze and it contained very little macrophyte litter. A very sparsely growing community of

P. vaginatus, *Myriophyllum*, and *Elodea* was present at this station during the summer and autumn, but the sediment was usually clear of fallen vegetation during winter months.

Stations 11 and 12 were very similar in all but depth. They were located to the south of the Wabamun intake canal. Station 11 was 4.5 m in depth and Station 12 was 6.0 m in depth. Both had ooze substrates and neither supported any vegetation.

Station 13 was located along the western portion of Point Alison. The depth of the water was 1.5 m and the substrate was mostly sand and gravel. *Scirpus validus* grew abundantly in the area and the substrate was covered with a thin, low growth of *Chara*. *P. vaginatus* was also present in low-growing patches.

IV. STATIONS FROM THE WEST END OF LAKE WABAMUN

The remaining six stations were located near Fallis in the western portion of the lake.

Station 14 was located along a sand beach on the eastern side of Fallis point at a depth of 1.5 m. *Chara* grew in low sprawling mats and *P. vaginatus* was present in small, low-growing clumps.

Station 15 was located near Station 14 at a depth of 3.0 m. The substrate was ooze. The sediment at this station contained very few plant remains and screened Eckman dredge samples from this station occupied only 50 ml to 75 ml. This was less than 10% of the volume occupied by the spring 1972 samples from Kapasiwin Bay, and only slightly in excess of the volume occupied by screened samples from Stations 16, 17, and 19 (4.5 m, 6.0 m, and 11.0 m) which generally contained no plant litter at all. Some plants did however grow at

Station 15 (*P. vaginatus* and *Myriophyllum*), but they were largely washed away from this station during autumn.

Stations 16, 17, 18, and 19 were located at depths of 4.5 m, 6.0 m, 8.0 m, and 11.0 m respectively. The substrate at all of these stations was ooze, and only at Station 18 did it contain some macrophyte remains. No vegetation was found growing at any of these stations.

MATERIALS AND METHODS

I. TEMPERATURE

Temperatures were measured with a YSI Thermistor. Temperature graphs were integrated by planimetry to obtain degree-day estimates. This was done for 14 of the sampling stations for both surface and substrate temperature data.

II. SAMPLING AND IDENTIFICATION

Most of the macroinvertebrate data were obtained from sediment grabs taken with an unmodified, 15 cm x 15 cm (0.023 m^2) Ekman dredge. In areas where vegetation cover or litter was extensive enough to prevent the efficient operation of the small dredge, a larger 22.5 cm x 22.5 cm (0.05 m^2) model was used. In situations where weed conditions would not permit grabs of sediment to be obtained in this manner, the following method was used. A diver, equipped with a weed sampling bag outfitted with a 0.150 mm screen bottom and a 0.10 m^2 quadrat, cut off a weed samples to within about 20.0 cm from the substrate. The large dredge was then hand operated by the diver in the area cleared of weeds. Nonquantitative sampling methods, such as anchor-towing for vegetation samples and dip-netting, were also employed at littoral stations. Ekman dredge grabs were treated as follows. The sample was first screened with either a 0.40 mm, 0.25 mm, or a 0.175 mm pore size screen. The samples were then taken back to the laboratory in plastic bags, Following this, any living plant material was rinsed, removed from the sample and weighed. The remainder of the sample was preserved in 70% ethanol.

Vegetation samples taken by both quantitative and non-quantitative methods were treated in the following manner. The samples were taken back to the laboratory in large plastic bags. Plant material was then rinsed a few strands at a time in a large tub of water to remove attached animals. Intact strands and complete plants were removed from the sample and weighed. After the rinsing and removal of the plants, the contents of the tub were screened through a 0.25 mm seive and preserved in 70% ethanol.

Organisms were picked from samples under 12X magnification from a dissecting microscope. In most cases macroinvertebrates could be identified under the dissecting microscope, but many of the chironomid larvae and the oligochaetes, polyvinyl lactophenol slide mounts were made and the specimens were examined under the compound microscope. In cases where a sample contained a great number of small organisms, only organisms from a subsample were mounted and examined. The number of specimens actually mounted depended on the number of species present within the sample. After all of the specimens which appeared to be different under the 50X magnification of the dissecting microscope had been examined on slide mounts, and after random sampling was no longer revealing more species, examination of the sample was terminated.

Species lists for each of the 19 stations were compiled from samples taken over a complete annual cycle. This usually involved sampling at 2-week to 1-month intervals during spring and summer and at 1- to 2-month intervals during autumn and winter months. Two to five replicate Ekman grabs together with vegetation samples (if any was present) were taken at each sampling time. The years for which sampling was carried out at each of the stations can be seen in Tables 2 to 6.

Collections of adult insects were made at several sites along the shoreline of the lake during the spring, summer, and early autumn of 1973, 1974, and 1975. Specimens were preserved in 70% ethanol. Chironomid imagoes were mounted on slides after macerating the head, thorax and abdomen with KOH. The mounting media used were Euparol and Polyvinyl lactophenol.

III. REARING OF INSECT LARVAE

In order to facilitate identification to the species level, many larval insects were reared to the adult stage. The following procedures were employed in the rearing of insect larvae.

A. CHIRONOMIDAE

Mature larvae and prepupae were taken from a sample and placed individually in 20 dr vials containing a little sediment and a few milliliters of lake water. The vials were covered with a gauze top and allowed to stand either at room temperature or in a 15°C water bath. In some cases, when a collection contained many apparently identical mature larvae, 10 to 30 individuals were placed in an aerated container of lake water of about 250 ml capacity, and provided with enough sediment to lightly cover the bottom. This sediment had been previously screened with a 0.145 mm screen to ensure that no larvae, or exuviae, were present within it. The tops of the containers were covered with gauze. Imagoes were collected and preserved about one day following their emergence. After all specimens had either emerged or died as immatures, the sediment was screened and all of the larval and pupal exuviae were collected and preserved.

Several of the smaller chironomids, including many of the Tanytarsini and Orthocladiinae, were never successfully reared. Consequently, many of these larvae could not be identified to the species level. Morphological groupings were erected for these larvae and each group was designated numerically, (e.g. *Cricotopus (Isocladius)* sp. #1, or *Tanytarsus* sp. #1, *et cetera*).

B. TRICHOPTERA

Attempts were made to locate sealed puparia of the various trichopterans during the season of their emergences. With the exception of the *Oecetis* species, such puparia always contained fragmented larval exuviae. These puparia were maintained in aerated vessels until emergence took place. The adult, pupal exuvium, and the puparium containing the fragmented larval exuvium were then preserved in 70% ethanol. Samples occasionally contained sealed puparia which contained a dead pharate adult together with the fragmented larval exuvium. The genitalia were generally fully developed within the abdomen of these pharate adults, permitting species identification.

The larvae, pupae, and adult stages of several species of caddis flies could not be associated in this manner. These included the psychomyids and the *Oecetis* species (Leptoceridae). The psychomyids do not build cases, and all attempts to handle them in the laboratory resulted in complete mortality prior to emergence. The *Oecetis* species eliminate the larval exuvium from the puparium and therefore must be handled individually from the ultimate instar. This was not successfully carried out, and only the species whose larvae are described in the literature could be identified with any certainty.

C. EPHEMEROPTERA

Several species of mayflies were reared in aquaria. After the appearance of the subimago on the gauze cover of the aquarium, the cast exuvium of the larva could usually be found on the surface of the water. If the subimago survived long enough to moult to the imago stage, these three stages could then be associated.

D. ODONATA

Several species of dragonflies were reared in laboratory aquaria. The exuvium of the ultimate larval instar was easily located within the tank and both that, and the adult animal were preserved together.

IV. WET WEIGHT DETERMINATION FOR CHIRONOMID LARVAE

Wet weights of chironomid larvae were determined by measuring the total length of a specimen and then estimating its weight from a length-wet weight curve. Length-weight curves were obtained for *Chironomus plumosus-plumosus* type, *C. atroviridis, Polypedilum nubeculosum* and *Tanytarsus* spp. The weights of individuals belonging to species other than these were estimated by using the same curves. The choice of curve depended upon the body shape of the species involved.

Curves were obtained by weighing blotter-dried specimens, that had been preserved in 10% formalin, on a Cahn electrobalance and subsequently measuring their lengths under a dissecting microscope equipped with an ocular micrometer. Large specimens were measured with a ruler.

Total wet-weight biomass for a species, for a sample, was obtained by estimating the weights of each specimen and summing them (if the number of specimens was small) or by deriving an estimate of the average weight of the individuals of that species (from a subsample) and multiplying this average by the number of specimens of that species.

TEMPERATURE REGIMES WITHIN LAKE WABAMUN

I. RESULTS

Figures 2 to 4 show the surface and substrate temperatures recorded at each of the stations from which year-around temperature data were taken. Table 1 gives degree-day comparisons between each station for (a) spring, summer, and autumn, (b) winter, and (c) the total annual period, for each year that temperature data were taken consistently at a given station. This table is a comparative summary of the temperature data taken at the 14 stations for which temperatures are plotted in Figures 2 to 4.

Stations 1, 2, 4. 6, 7, and 8 were kept ice-free by the thermal effluents during all winters of this study. Intermittent thin ice formed at Station 5, but it was not usually thick enough to deny access by boat. At Station 3, thin ice was usually always present during winter, and conditions were such as to deny access by boat or from shore. Consequently year-around temperature data were never obtained from this station.

The temperatures recorded from Station 1 during the time interval from May, 1973 to August, 1975 are shown in Figure 2A. Surface temperatures recorded at this station were generally only about one degree lower than those recorded half-way down the canal itself. Despite the shallowness of this station (1.5 m) significant surface to substrate temperature differentials were observed. As the flowing heated water leaving the canal encountered the cooler lake water a shear tended to develop, with the flowing heated waters being

Table 1

A comparative summary of the surface and substrate temperature data from 14 stations.

The values given are degree-day estimates for (a) spring, summer plus autumn, (b) winter (November 15 - April 1) and (c) the total annual period denoted.

Station #	Depth	Time Interval	(a)		(b)		(c)	
			Sfc.	Substr.	Sfc.	Substr.	Sfc.	Substr.
1	1.5m	May 1, 1973-74	5256	4184	1640	1015	6896	5199
		May 1, 1974-75	5142	4296	1860	1115	7002	5411
		Aug.15,1974-75	5249	4614	1860	1115	7109	5729
7	1.5m	Sept.1,1974-75	4686	3810	1595	985	6281	4795
2	1.5m	May 15,1972-73	3884	3373	975	552	4859	3925
9	1.5m	June15,1973-74	3068	3003	30	286	3098	3289
		June15,1974-75	3135	2993	48	190	3161	3183
14	1.5m	Sept.1,1974-75	2907	2950	0	300	2907	3250
4	3 m	May 1, 1973-74	4587	3248	1503	612	6090	3860
		May 1, 1974-75	4530	3312	1836	465	6366	3777
		Aug.15,1974-75	4360	3397	1836	465	6196	3862
5	2.5m	May 1, 1973-74	3479	2883	383	512	3862	3395
		May 1, 1974-75	3496	3027	535	495	4031	3522
		Aug.15,1974-75	3454	2921	535	495	3989	3416
8	3 m	June20,1974-75	3459	2954	360	420	3819	3374
10	3 m	Sept.1,1974-75	3022	2720	55	420	3077	3140
6	4.5m	May 15,1972-73	3960	2838	1493	580	5453	3416
		May 15,1973-74	4265	2859	828	536	5093	3395
		May 15,1974-75	4179	2951	935	444	5114	3395
		Aug.15,1974-75	4201	3099	935	444	5136	3543
16	4.5m	June 6,1972-73	2779	2536	0	456	2779	2992
		Oct.31,1972-73	2886	2557	0	456	2886	3013
		May 18,1974-75	2822	2575	0	417	2822	2992
		Aug.15,1974-75	2801	2587	0	417	2801	3004
17	6 m	May 18,1974-75	2564	2494	0	519	2864	3013
		Aug.15,1974-75	2758	2473	0	519	2758	2992
18	8 m	May 18,1974-75	2801	2410	0	560	2801	2970
		Aug.15,1974-75	2843	2410	0	560	2843	2970
19	11 m	May 18,1974-75	2801	2251	0	571	2801	2822
		Aug.15,1974-75	2801	2272	0	571	2801	2843

Stations are grouped into depth categories (1.5 m, 2.5 - 3 m, 4.5 m, 6 m, 8 m and 11 m) with stations situated near heated discharges listed first for each depth category. Stations 1, 2, 4, 5, 6, 7 and 8 were ice-free during winter periods.

confined to a layer about 1 m in thickness at the water surface. The fact that this station was rather sheltered from all but east and south winds, which are both generally of a mild nature on this lake, hindered the wind and wave agitation required to upset this stratification.

Surface to substrate temperature differentials observed at Station 1 were at all times less pronounced during summer than they were during winter. Summer vertical differentials were of the order of 1°C to 3°C, whereas winter vertical differentials were often as great as 5°C to 6°C.

The summer surface temperatures recorded at this station were twice found to be in excess of 30.0°C. The maximum temperature recorded at the substrate was 28.1°C. Summer temperatures were usually between 20°C and 29°C at the surface, and between 24°C and 27°C at the substrate. Winter surface temperatures were generally between 12°C and 14°C at the surface, and between 6°C and 9°C at the substrate.

The seasonal pattern of temperature change at this station was not much different from that observed at other stations of the same depth. The sharpest rate of increase tended to occur during early, to mid-May, and the most pronounced rate of decrease occurred during the month of September.

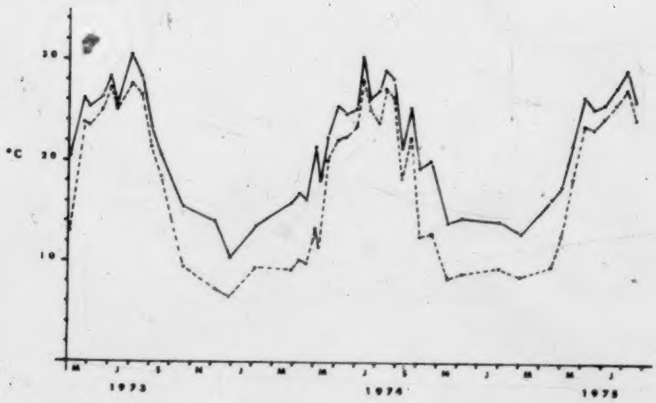
Surface and substrate temperatures recorded at Station 2 (Fig. 2D) were much lower than those recorded during corresponding seasons at Station 1. This station was located about 200 m to the

Figure 2. Surface (solid line) and substrate (dashed line) temperatures for Stations 1, 7, 4, 2, 5, and 8 (A-F).

Stations 1, 2 and 7 were 1.5 m deep.

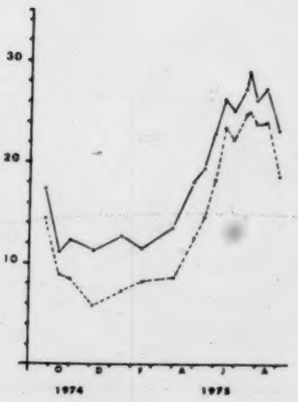
Station 5 was 2.5 m. deep.

Stations 4 and 8 were 3.0 m deep.



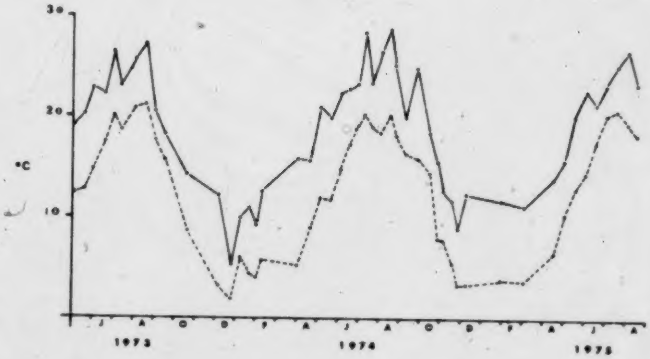
Stn. 1

A



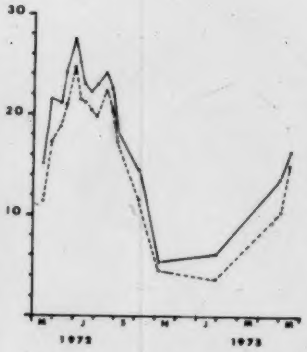
Stn. 7

B



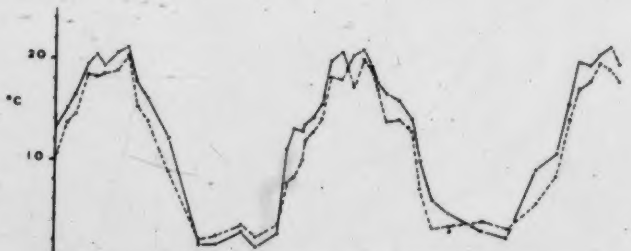
Stn. 4

C



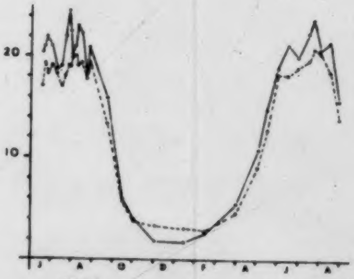
Stn. 2

D



Stn. 5

E



Stn. 8

F

east and north of the Wabamun discharge, and it did not receive the direct flow of the heated effluent. Table 1 shows that the temperatures recorded at Station 2 were intermediate among the 1.5 m stations. They were lower than those recorded at Stations 1 and 7, and substantially higher than those recorded at Stations 9 and 14. Surface to substrate temperature differentials at Station 2 were generally of a lower magnitude than those observed at Station 1. This is probably related to the fact that this station does not receive the direct surface current from the discharge.

Although temperatures were not recorded frequently enough at Station 3 for the degree-day parameters to be calculated for this station, on nine occasions temperatures were measured within hours at Stations 3 and 9. On the average, surface temperatures at Station 3 exceeded those at Station 9 by 0.6°C, and substrate temperatures at Station 3 exceeded those at Station 9 by an average of 0.2°C. Stations 9 and 14 were both located outside of the bays which received thermal effluents and both experienced a normal duration of ice cover.

Station 4, which was located in a direct line with the flow from the Wabamun thermal discharge, was characterized by extremely pronounced surface to substrate temperature differentials at all seasons. Surface temperatures ranged from 4°C to 10°C higher than substrate temperatures (Fig. 2C). Temperature profiles generally showed the heated waters at Station 4 to be confined to a region of surface flow occupying the upper 1.0 m to 1.5 m of the water column. The protected nature of the area near the Wabamun discharge served prevent the agitation of the water column required to upset this stratification.

The limited vertical exchange of heat at Station 4 permitted substrate temperatures to remain much nearer normal for the 3.0 m depth, than was the case for the surface temperatures (Table 1). Both surface temperatures and substrate temperatures recorded at Station 4 were higher than those recorded at any other station of 3.0 m depth.

Temperatures recorded at Station 5 (Fig. 2E) were lower than those recorded at Station 4, both at the surface and at the substrate. Table 1 shows that temperatures at Station 5 were about equivalent to those recorded at Station 8 (3.0 m) and markedly higher than those recorded at Station 10 (3.0 m). It is interesting to note that the maximum surface temperature recorded at Station 5 (22.5°C) and the maximum substrate temperature (20.2°C) were practically identical to the respective maxima recorded at Station 10 (Fig. 3C). This reflects the fact that the higher number of degree-days accumulated at Station 5 was mainly a consequence of the earlier spring rise in temperatures which took place in the absence of winter ice cover.

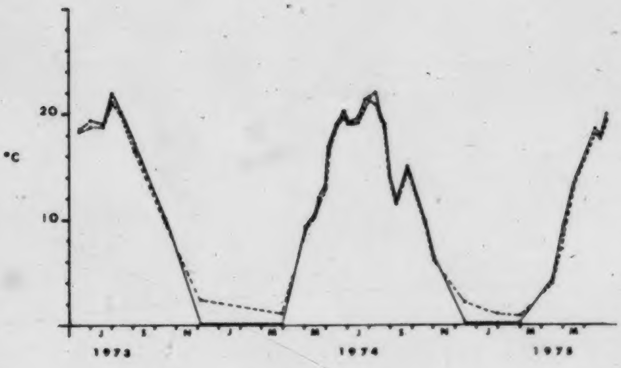
During the winter months Station 5 was generally close enough to freezing over for inverted temperature profiles to be recorded. Surface temperatures under such conditions were generally about 1°C lower than substrate temperatures. Inverted profiles were recorded on each winter recording date during 1973-74, and on two occasions during the winter of 1974-75.

Figure 3. Surface (solid line) and substrate (dashed line) temperatures for Stations 9, 6, and 10 (A-C).

Station 9 was 1.5 m deep.

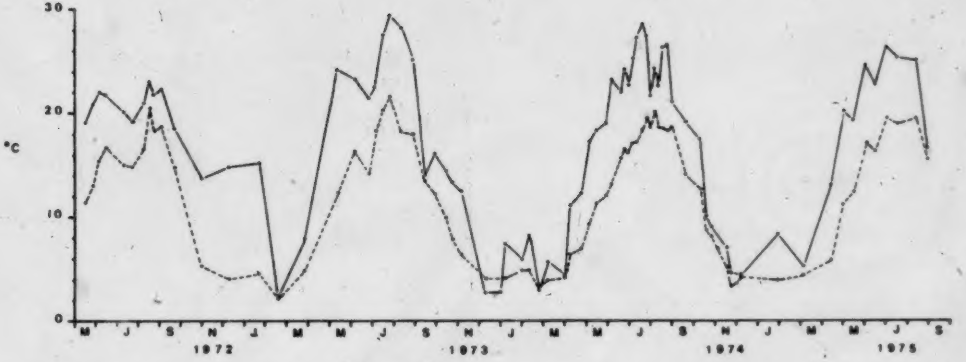
Station 10 was 3.0 m deep.

Station 6 was 4.5 m deep.



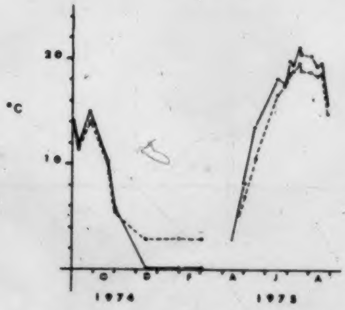
Stn. 9

A



Stn. 6

B



Stn. 10

C

Surface temperatures as high as 28.9°C were recorded at Station 6 (Fig. 3B), but for the most part the surface temperatures ranged between 23°C and 25°C during summer periods. Despite high surface temperatures, substrate temperatures were almost never in excess of 20°C. Vertical heat exchange at this station, although probably more significant than at Station 4, was not significant enough to abolish the strong surface to substrate temperature differentials. These vertical differentials were between 5°C and 10°C during summer, but were usually of a much lower magnitude during winter (Fig. 3B).

Profiles taken at this station on days when wave action was moderate to strong showed a gradual, almost linear decrease of temperature down to about the 3.0 m level, with a sharper decrease below that point. Profiles taken on calm days showed warm water to be confined to the top 1.0 m to 1.5 m of the water column with an extremely abrupt decrease in water temperature below that point.

Both surface and substrate temperatures from Station 6 exceeded those recorded at Station 16 (Fig. 4A). Maximum substrate temperatures recorded during the summers were practically identical, but Station 6 accumulated many more degree-days than Station 16 (Table 1) because of the earlier warming during spring, that occurred at all of the station that were not frozen over during the winter months.

The highest surface temperature recorded at Station 7 was 29.0°C, and the highest substrate temperature was 25.0°C (Fig. 2B). Surface and substrate temperatures at Station 7 (in the discharge plume from the Sundance station) were usually about 1°C to 2°C lower

Figure 4. Surface (solid line) and substrate (dashed line) temperatures for Stations 16, 14, 17, 18, and 19 (A-E).

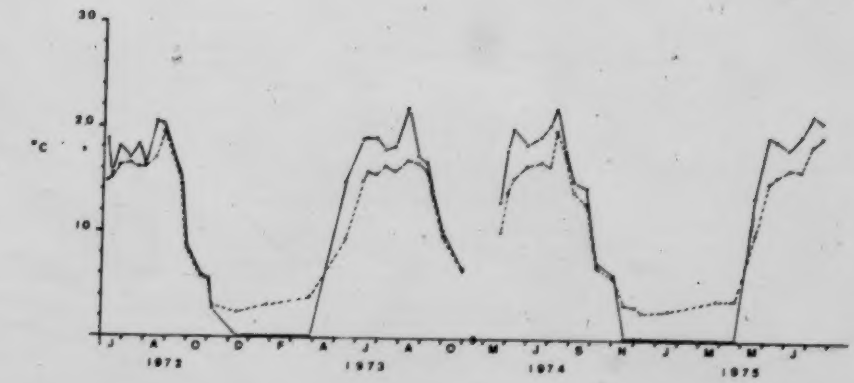
Station 14 was 1.5 m deep.

Station 16 was 4.5 m deep.

Station 17 was 6.0 m deep.

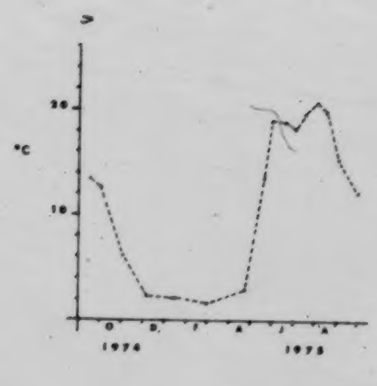
Station 18 was 8.0 m deep.

Station 19 was 11.0 m deep.



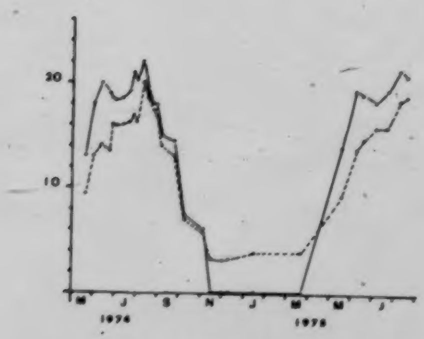
Stn. 16

A



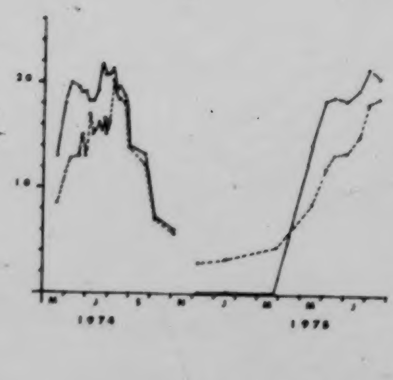
Stn. 14

B



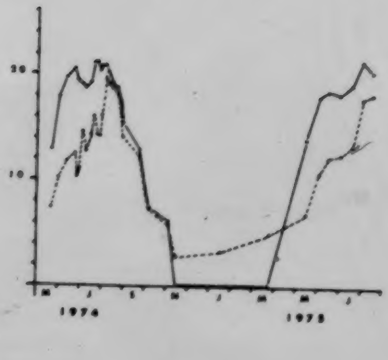
Stn. 17

C



Stn. 18

D



Stn. 19

E

than those recorded on the same day at Station 1 (in the plume from the Wabamun station). Surface to substrate temperature differentials were very nearly the same at Station 1 and 7, and the seasonal variation was also similar.

Table 1 shows that Station 7 accumulated fewer degree-days over a 1-year period than did Station 1, both at the surface and at the substrate. Station 2 accumulated far fewer degree-days for a 1-year period than did Station 7. Stations 1, 2, and 7 all accumulated more degree-days than Stations 9 and 14, at all times of the year, both at the surface and at the substrate (Table 1).

The surface temperatures recorded at Station 8 were not nearly as high as those recorded at stations situated in line with the Wabamun discharge (Stations 4 and 6). The maximum surface temperature recorded at Station 8 was 24.5°C and the maximum substrate temperature was 20.0°C (Fig. 2F). Most summer temperatures were between 20°C and 23°C at the surface, and around 18°C to 20°C at the substrate. Table 1 shows that the surface temperatures were cumulatively about 1400 degree-days per year warmer at Station 6 than they were at Station 8, despite the fact that Station 6 was much farther away from the mouth of its discharge canal. The number of degree-days at the substrate was about the same at the two stations despite the greater depth of Station 6.

The surface to substrate temperature differentials varied from less than 1°C to over 5°C at Station 8. On calm days the differential was very pronounced and the profiles indicated that warm water was being confined to the surface layers. On windy days the temperature differentials were often almost completely abolished, but normally a more or less linear temperature profile was encountered with a vertical differential of about 2°C. At Station 6, winds and their mixing usually resulted in a warming effect at the substrate. Due to the more exposed condition of the Sundance discharge area, winds tended to disperse the thermal plume at a point much nearer the discharge. Consequently, at Station 8 the effect of wind was more often a lowering of the surface temperature.

On the basis of the cumulative temperature parameters shown in Table 1, Station 8 was very similar to Station 5, and both stations accumulated slightly more degree-days, at both surface and substrate, than did Station 10. Summer substrate temperatures at Station 8 did not exceed those recorded at the same time at Station 10, but earlier warming during spring resulted in the cumulative substrate temperatures for Station 8 being in excess of those calculated for Station 10. Winter substrate temperatures were also slightly higher at Station 8 than they were at Station 10, which was under ice. During winter Station 8 was sufficiently close to freezing over for the temperature profiles to invert and bring surface temperatures 1°C to 2°C below those of the substrate.

Stations 9 and 10 were located near the water intake canal for the Wabamun power station, and their depths were 1.5 m and 3.0 m respectively. Both of these stations received in excess of 5 months of ice cover each winter. Ice breakup in the area of Stations 9 and 10 usually only preceded that at Fallis (Stations 14, 15, and 16) by about 10 days. The maximum surface temperature recorded was 21.8°C (Fig. 3A). Summer temperatures at this station were generally within the range of 19°C to 21°C at both the surface and the substrate. The surface to substrate temperature differentials were about 0.5°C to 1.0°C during the ice-free season, which was markedly less than that observed at any station near the heated discharge sites. Winter substrate temperatures were very low at this station, and they reached levels as low as 1.0°C during January and February.

Althouth Stations 9 and 14 were both 1.5 m deep, and both received ice cover, the number of degree-days estimated for Station 9 at the substrate was slightly in excess of that estimated for Station 14. This appeared to be due mainly to the slightly earlier spring thaw at Station 9.

Station 10 had practically identical surface temperatures to those recorded at Station 9. The substrate temperatures recorded during the ice-free season were generally about 0.5°C to 1.0°C lower at Station 10 (Fig. 3C) than those recorded at Station 9. Consequently, the surface to substrate temperature differentials were somewhat more pronounced at Station 10 than they were at Station 9. They were not, however, nearly as pronounced as those observed at Stations 4 and 8, which were 3.0 m stations situated near thermal discharges. The cumulative temperature parameters estimated for Station 10 (Table 1) were lower than the corresponding values for the 3.0 m stations situated within the bays which received thermal effluents.

Stations 14, 16, 17, 18, and 19 were located near Fallis in the western portion of the lake at depths of 1.5 m, 4.5 m, 6.0 m, 8.0 m, and 11.0 m respectively. These stations all received a greater duration of ice cover than did Stations 9 and 10 in the eastern portion of the lake. The surface and substrate temperatures at Station 14 were so nearly identical at all times during the ice-free season that only the latter were plotted (Fig. 4B). The maximum surface temperature recorded at this station was 20.8°C; and for most of the summer, temperatures at this station ranged between 18°C and 20°C, both at the surface and at the substrate. The under-ice substrate temperatures at Station 14 were slightly higher than those recorded at Station 9, but again there was a slight decreasing trend as the winter progressed. Shortly before the ice went out at this station, substrate temperatures rose from 1.8°C to 3.1°C.

The surface temperatures at Stations 16, 17, 18, and 19 were very similar to each other and to the temperatures recorded at Station 14 (Figs. 4A, C, D, and E). During the summer of 1974, temperatures were recorded from the station marked 18a. All of these stations were characterized by pronounced surface to substrate temperature differentials from mid-May till early August. At this time temperatures within the water column were almost uniform. This condition persisted throughout the cooling phase of the season. During the mid-May to early August period, substrate temperatures increased fairly constantly despite fluctuations at all depths. During this warming phase, substrate temperatures varied inversely with depth, with Station 19 being about 4°C cooler than Station 16 for most of this interval. The cooling phase lasted from mid-August until freeze-up and during this phase the substrate temperatures at these four stations were almost identical.

When ice cover set in, the temperatures at the substrate were 3°C or less at all of these stations. Over the winter there occurred notable increases in the substrate temperatures at these stations, and the values recorded in the later part of the winter varied directly with depth, with Station 19 reaching temperatures above 5°C at the substrate. Both Stations 18 and 19 had substrate temperatures in excess of 4°C from March, 1975, until the ice went out in early May.

Table 1 shows that with regard to the number of degree-days for spring, summer and autumn, at the substrate, Stations 16, 17, 18 and 19 were ranked in the order of their depth, with Station 16 the warmest. Under ice, the situation was reversed (Table 1).

At these 4 deep stations, the warming of the bottom water lagged markedly behind the warming of the surface water. This was an interesting observation in view of the shallow and well agitated nature of Lake Wabamun. The nature of the thermal stratification associated with the surface to substrate temperature differentials can be seen from the temperature profiles shown in Figures 5 to 8, which show temperature profiles from Stations 17, 18, and 19 (Stations 4, 5, and 7 in Nuttall, 1974) taken on a series of dates during the interval from June 24 to August 20, 1974.

The temperature profiles from June and July (Figs. 5, 6, and 7) all show marked vertical differentials. These differentials increased in magnitude with depth and declined in magnitude over the time interval. The points of strongest inflection in the profile curves occurred at the greatest depth at Station 19 and at the shallowest depth at Station 17, rather than at the same depth at all stations.

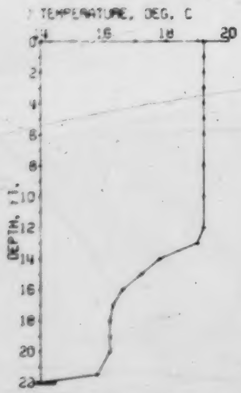
By August, (Fig. 8), the profiles became extremely uniform throughout the water column and during this month the surface to substrate temperature differentials were very slight at all depths. Temperature differentials between the surface water and the substrate were generally minimal during the cooling phase of the season. During this phase it was quite often noted that the substrate temperatures were higher than those recorded throughout the remainder of the water column. Figures 9, 10, and 11 show profiles taken from various locations in Lake Wabamun by Nuttall (1974) on three different dates during the autumn of 1973, when this was observed.

Figures 4A, C, D, and E show that temperatures at the substrate under ice cover were steadily increasing throughout the course of the winter, at stations of greater than 4.0 m depth. At Stations 18 and 19 these temperatures were observed to be in excess of 4.0°C by March, 1975. Figure 12 shows profiles recorded by Nuttall (1974) on February 16, 1974, near Fallis which show that at depths greater than 25 ft, the substrate temperatures were uniformly in excess of 4.0°C, and at the deepest locations, even higher than 5.0°C.

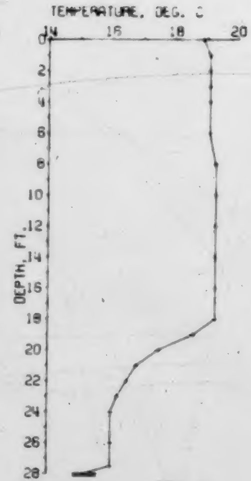
A. COMPARISONS BETWEEN STATIONS USING CUMULATIVE TEMPERATURE DATA (Table 1)

The relationship between depth and the cumulative temperature parameters can be seen by a comparison of the series of stations

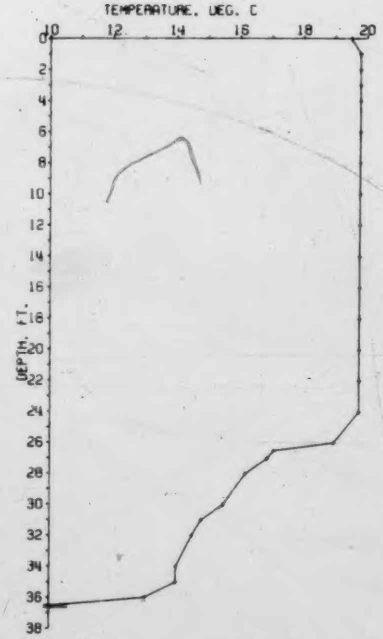
Figure 5. Temperature profiles for June 24 and June 27, 1974 at Stations 17, 18, and 19.



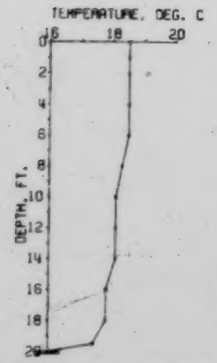
JUNE 24 1974 STN 17



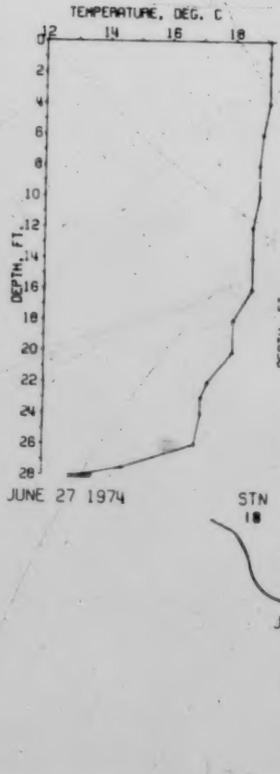
JUNE 24 1974 STN 18



JUNE 24 1974 STN 19

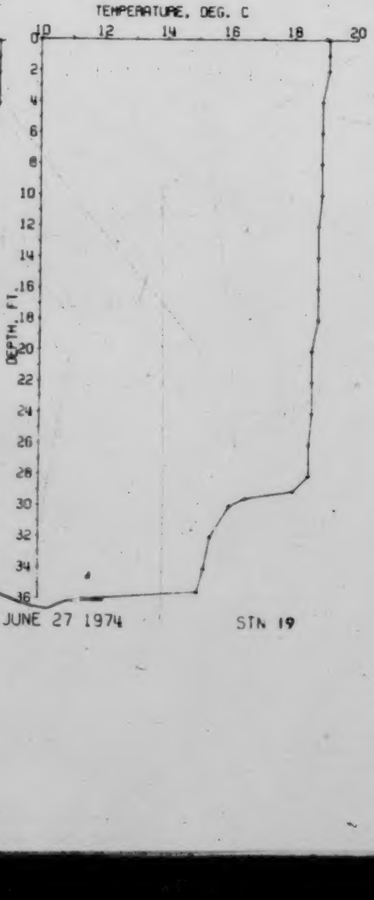


JUNE 27 1974 STN 17



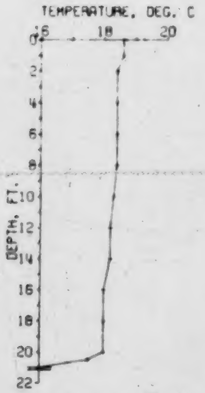
JUNE 27 1974

STN
18

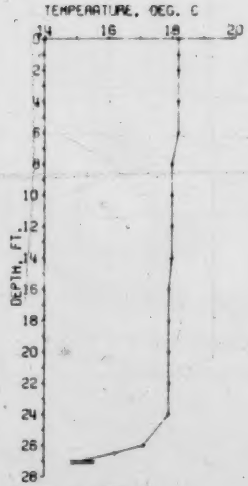


JUNE 27 1974 STN 19

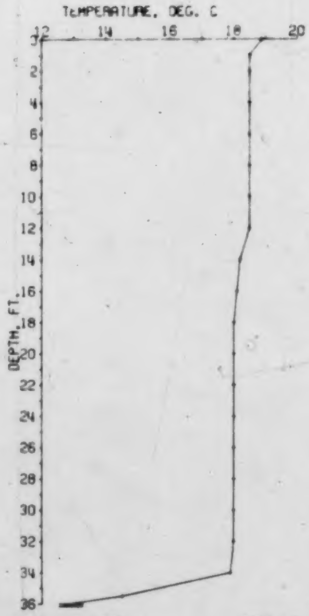
Figure 6. Temperature profiles for July 8 and July 15, 1974 at Stations 17, 18, and 19.



JULY 8 1974 STN 17



JULY 8 1974
STN 18



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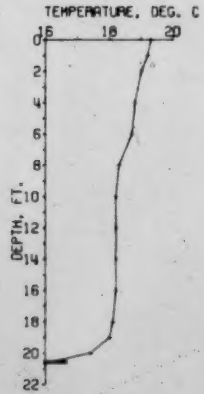
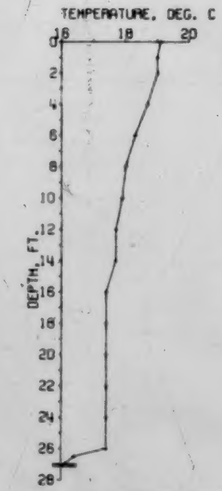
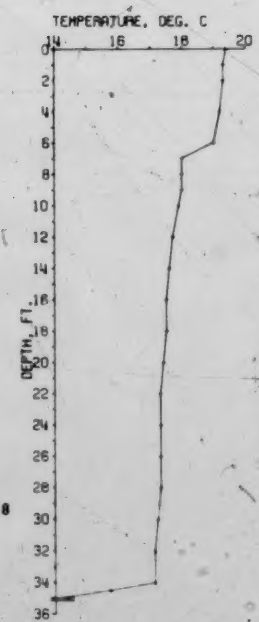


JULY 15 1974
11:37HRS STN 17

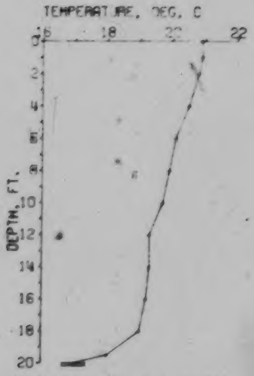


JULY 15 1974 11:54HRS STN 18

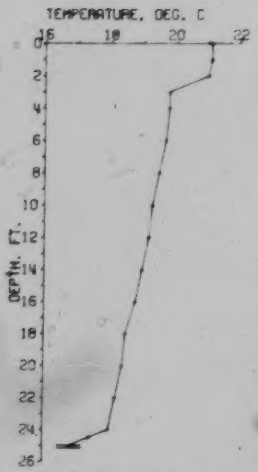


JULY 15 1974 13:06HRS STN 19

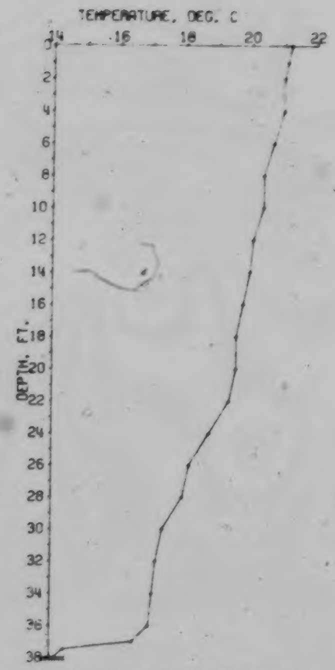
Figure 7. Temperature profiles for July 23 and July 30, 1974 at Stations 17, 18, and 19.



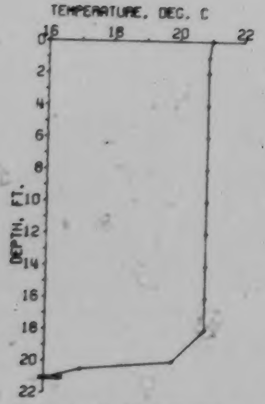
JULY 23 1974 16:10HRS
STN 17



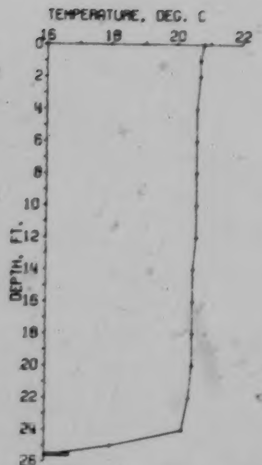
JULY 23 1974 16:30HRS
STN 18



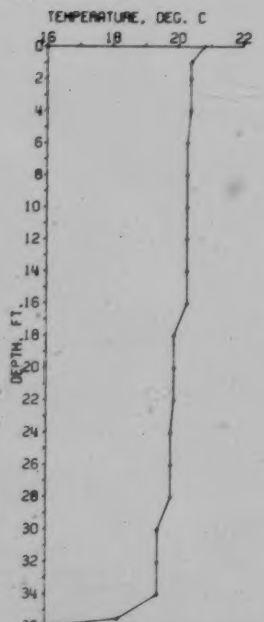
JULY 23 1974 17:00HRS STN 19



JULY 30 15:25 HRS STN 17

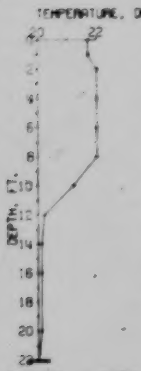


JULY 30 15:45 HRS STN 18

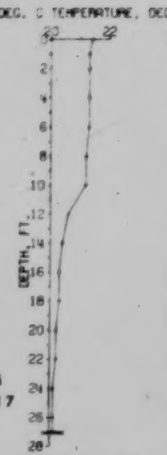


JULY 30 16:37 HRS STN 19

Figure 8. Temperature profiles for August 5, August 9, August 13, and August 20, 1974 at Stations 17, 18, and 19.



AUGUST 5 1974
14:34HRS STN 17



AUGUST 5 1974
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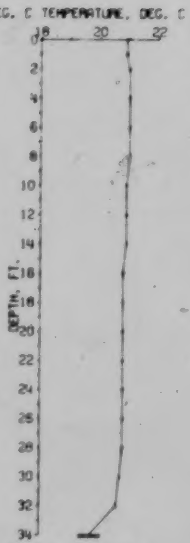

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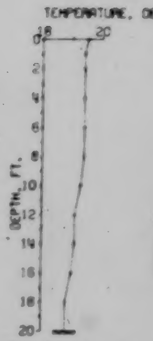
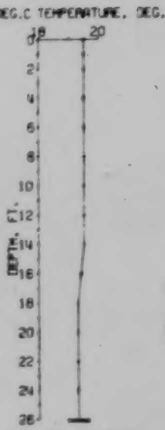
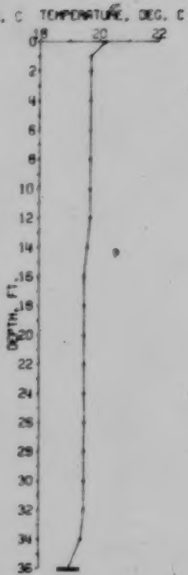


AUGUST 9 1974
18:22HRS STN 17



AUGUST 9 1974
18:07HRS STN 18



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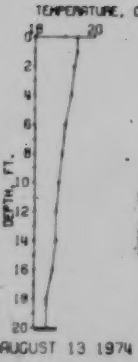

AUGUST 13 1974
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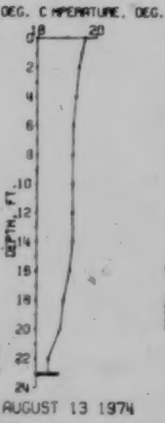

AUGUST 13 1974
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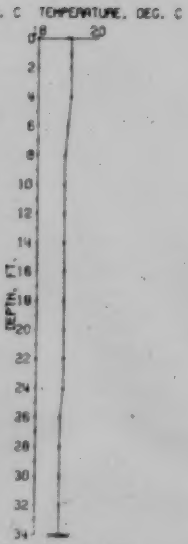

AUGUST 13 1974
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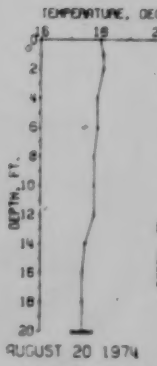
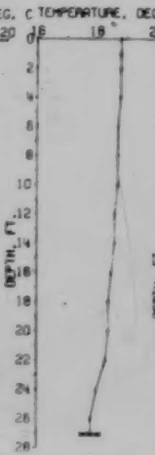
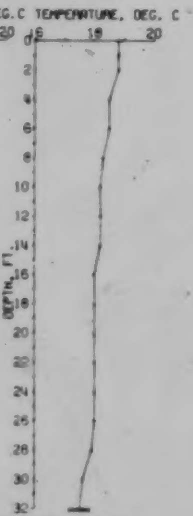


AUGUST 20 1974
13:45HRS STN 17

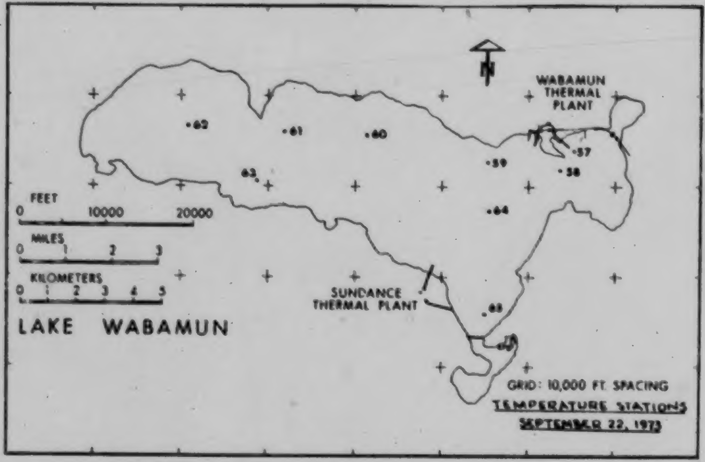


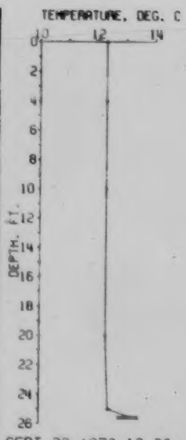
AUGUST 20 1974
13:59HRS STN 18



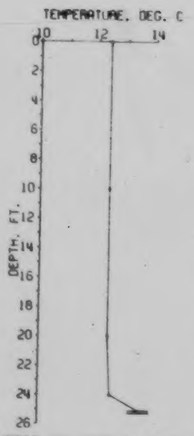
AUGUST 20 1974
14:50HRS STN 19

Figure 9. Temperature profile from 9 locations on Lake Wabamun for September 22, 1973. (After Nuttall, 1974, with revisions).

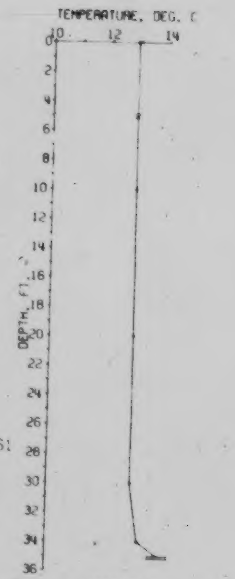

WABAMUN THERMAL PLANT
SUNDANCE THERMAL PLANT
N
•57
•58
•59
•60
•61
•62
63
•64
•65
FEET
0 10000 20000
MILES
0 1 2 3
KILOMETERS
0 1 2 3 4 5
LAKE WABAMUN
GRID: 10,000 FT. SPACING
TEMPERATURE STATIONS
SEPTEMBER 22, 1973



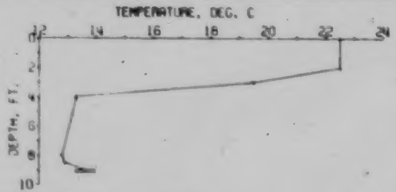
SEPT 22 1973 13:22 *60*



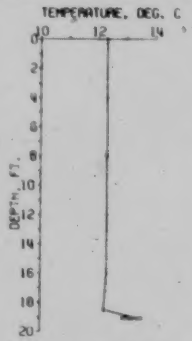
SEPT 22 1973 13:34 *61



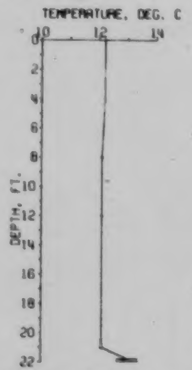
SEPT 22 1973 13:45 *62*



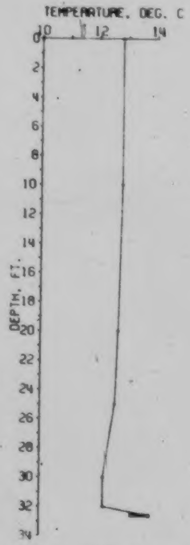
SEPT 22 1973 12:25 *57*



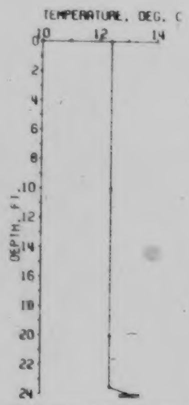
SEPT 22 1973 12:36 *58*



SEPT 22 1973 13:10 *59*



SEPT 22 1973 14:01 *63*



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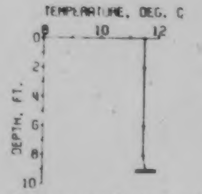
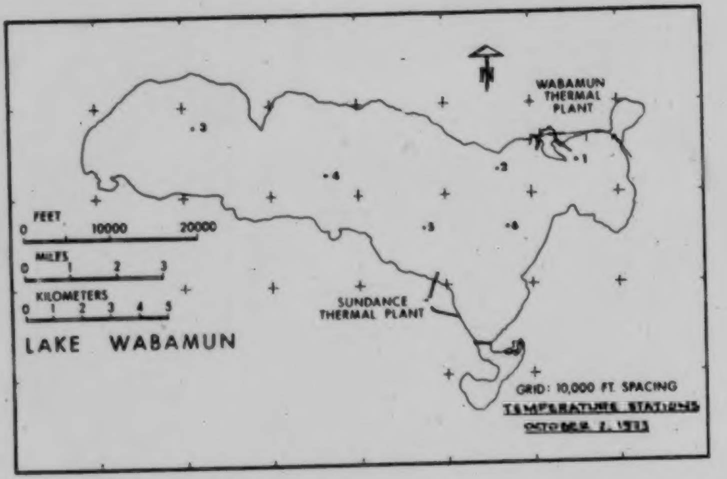


SEPT 22 1973 14:37 *65*

Figure 10. Temperature profiles from 6 locations on Lake Wabamun for October 2, 1973. (After Nuttall, 1974, with revisions).


N
WABAMUN THERMAL PLANT
SUNDANCE THERMAL PLANT
1
2
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4
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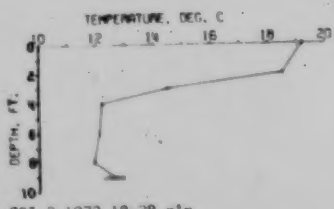
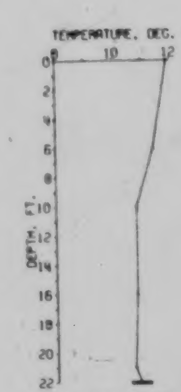
6
FEET
0 10000 20000
MILES
0 1 2 3
KILOMETERS
0 1 2 3 4 5
LAKE WABAMUN
GRID: 10,000 FT. SPACING
TEMPERATURE STATIONS
OCTOBER 2, 1973



OCT 2 1973 18:28 #1#



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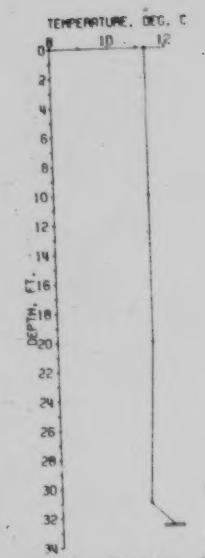

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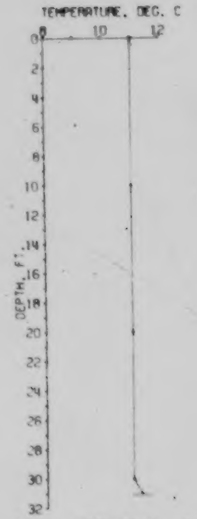

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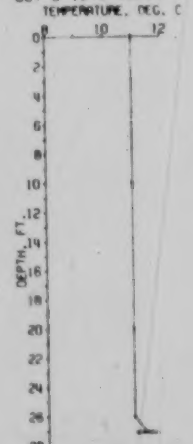

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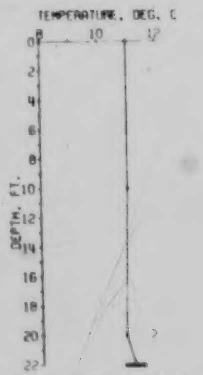
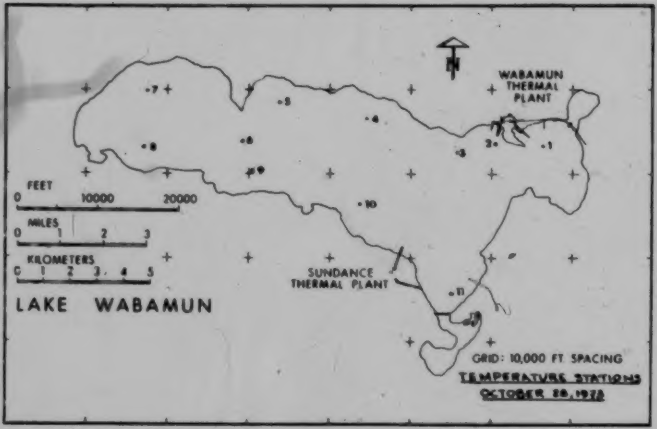
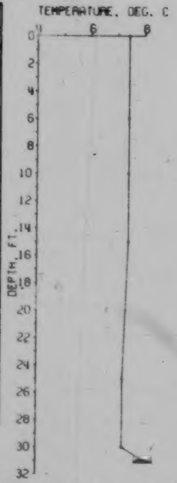


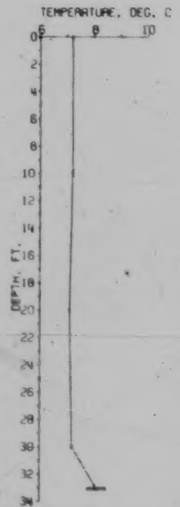
OCT 2 1973 20:15 #6#

Figure 11. Temperature profiles from 11 locations on Lake Wabamun for October 28, 1973. (After Nuttall, 1974, with revisions).

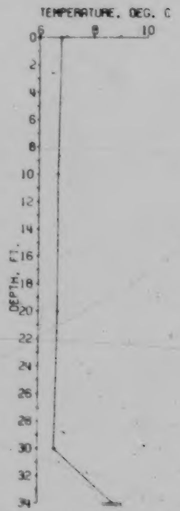

WABAMUN THERMAL PLANT
SUNDANCE THERMAL PLANT
N
FEET
0 10000 20000
MILES
0 1 2 3
KILOMETERS
0 1 2 3 4 5
LAKE WABAMUN
GRID: 10,000 FT. SPACING
TEMPERATURE STATIONS
OCTOBER 28, 1973
1
2
3
4
5
6
7
8
9
10
11



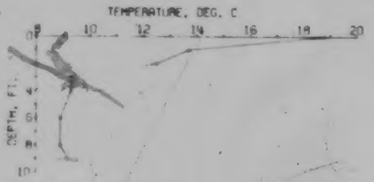
OCT 28 1973 11:50 *6*



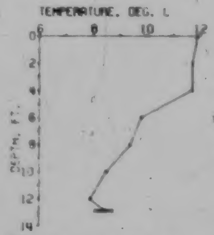
OCT 28 1973 12:03 *7*



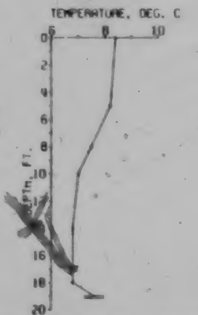
OCT 28 1973 12:12 *8*



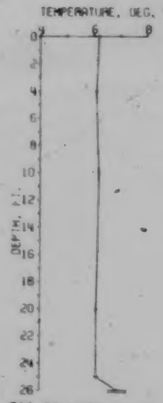
OCT 28 1973 14:11 *1*



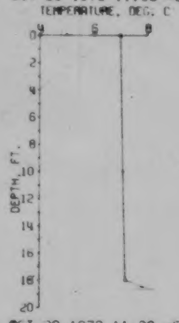
OCT 28 1973 10:46 *2*



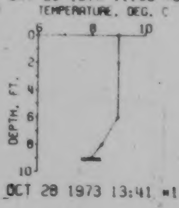
OCT 28 1973 11:06 *3*



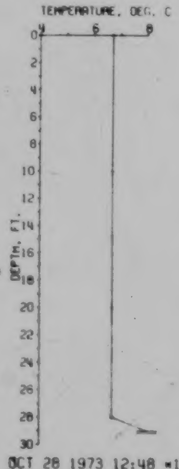
OCT 28 1973 11:24 *4*



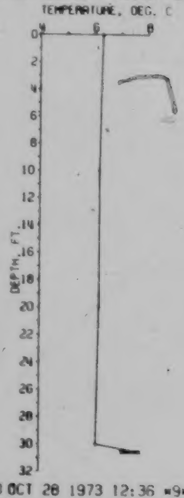
OCT 28 1973 11:38 *5*



OCT 28 1973 13:41 *11

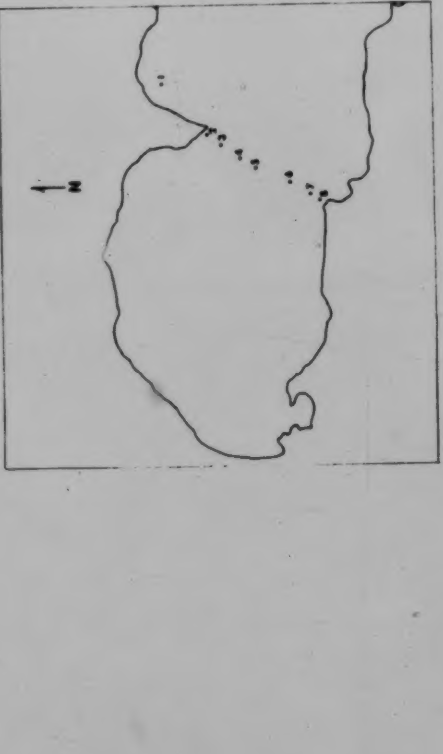


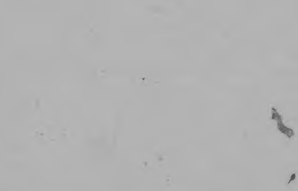
OCT 28 1973 12:48 *10



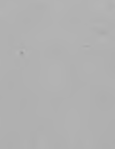
OCT 28 1973 12:36 *9*

Figure 12. Under-ice temperature profiles from 8 locations near Fallis Point for February 16, 1974. (After Nuttall, 1974, with revisions).

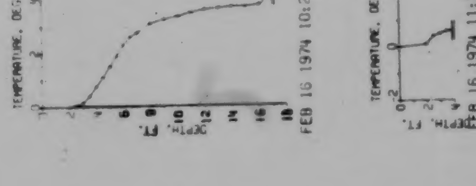




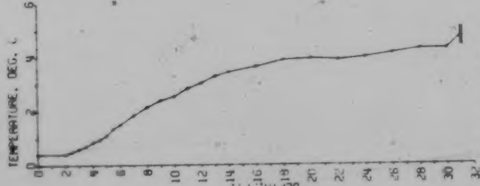
FEB 16 1974 10:27 *1*



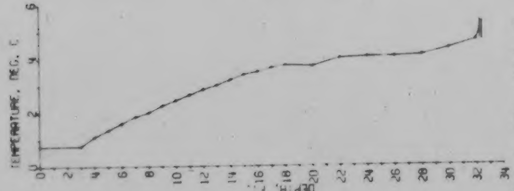
FEB 16 1974 11:30 *2*



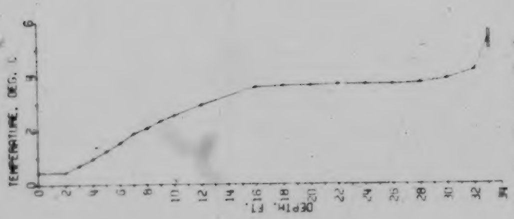
FEB 16 1974 12:13 *3*



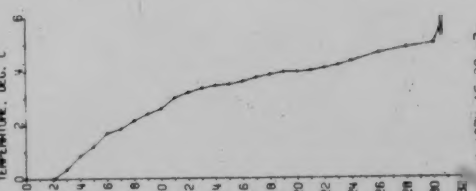
FEB 16 1974 12:55 *4*



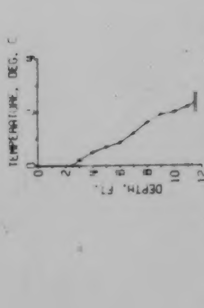
FEB 16 1974 13:50 *5*



FEB 16 1974 14:40 *6*



FEB 16 1974 15:30 *7*



FEB 16 1974 16:15 *8*

including Stations 14, 16, 17, 18, and 19. None of these stations appear to be affected by the thermal effluents.

These 5 stations rank in reverse order with depth (Station 14 > Station 16 > Station 17 > Station 18 > Station 19), with regard to degree-days per year at the surface. The differences between these stations in surface temperatures were slight. With regard to spring, summer, and autumn substrate temperatures, the stations ranked in the same order with the differences being much more pronounced for this parameter.

Cumulative winter substrate temperatures showed a direct variation with depth with Station 19 ≈ Station 18 > Station 17 > Station 16 > Station 14. Therefore, for winter cumulative substrate temperatures, these stations ranked in reverse order to the ranking obtained for spring, summer and autumn surface and substrate temperatures.

The stations from the east end of the lake can then be compared with the previously ranked stations from the west end of the lake. For cumulative spring, summer and autumn surface temperatures, the stations of 1.5 m depth ranked as follows: Station 1 (5142-5256) > Station 7 (4686) > Station 2 (3884) > Station 9 (3068-3165) > Station 14 (2907). These values represent the estimated number of degree-days per year, and the values appear in Table 1. For winter surface temperatures the rank relationship among these stations is the same.

The ranking obtained for 1.5 m stations with regard to cumulative spring, summer and autumn substrate temperatures was again the same. Station 1 (4184-4614) > Station 7 (3810) > Station 2 (3373) >

Station 9 (2993-3003) > Station 14 (2950). For spring, summer and autumn, surface and substrate cumulative temperature parameters, the small amount of data collected at Station 3 (page 51) suggest that this station should rank below Station 2 and above Station 9. For cumulative winter substrate temperatures, Station 1 (1015-1115) > Station 7 (985) > Station 2 (552) > Station 14 (300) > Station 9 (190-286).

For cumulative spring, summer and autumn surface temperatures, the stations of 2.5 m - 3.0 m depth ranked as follows: Station 4 (4360-4587) > Station 5 (3454-3496) ≈ Station 8 (3459) > Station 10 (3022). The stations ranked in the same order for winter cumulative surface temperatures. With regard to spring, summer and autumn substrate temperatures, Station 4 (3212-3397) > Station 5 (2883-3027) ≈ Station 8 (2954) > Station 10 (2720). Winter cumulative substrate temperatures showed very little difference between these four stations.

Two 4.5 m stations were studied for 4 consecutive years, and Station 6 (center of Kapasiwin Bay) always exceeded Station 16 (Fallis) in all of the cumulative temperature parameters. For spring, summer, and autumn surface temperatures, Station 6 accumulated from 3960 to 4265 degree-days per yearly period, as compared to 2779 to 2886 for Station 16. In cumulative spring, summer and autumn substrate temperatures, the difference between the two stations was equally as consistent, though not as great. Station 6 accumulated from 2838 to 3099 degree-days per year, as compared to 2536 to 2587 for Station 16.

Station 6 was ice-free during all winter periods of the study and consequently it exceeded Station 16 in winter surface temperatures, since the latter station was frozen over during each winter. For winter substrate temperatures the two stations were almost equal. Station 6 was estimated to have accumulated from 444 to 580 degree-days for the winter period as compared to 417 to 456 for Station 16.

II. DISCUSSION

The data obtained from the temperature studies showed that Stations 1, 2, 3, 4, 5, and 6 from Kapasiwin Bay, and Stations 7 and 8 from Indian Bay had higher temperatures both at the surface and at the substrate, than other stations of comparable depths. The temperature elevation (Table 1) was more pronounced at the surface than it was at the substrate, and hence the vertical temperature differentials at these stations were of a greater magnitude than those encountered at stations distant from the heated discharges, and of comparable depth.

The elevation of substrate temperatures at stations in line with the flow of heated water from the discharge canals, (Stations 1, 4, 6, 7, and 8) was inversely related to depth, due to the fact that the discharge canals emptied into very shallow locations. Heated waters did not influence the areas of Station 6 and Station 8 until considerable mixing had occurred. Consequently, only at Stations 1 and 7 (1.5 m) could the effects of strong (5°C to 8°C) temperature elevations be studied.

All of the stations of Kapasiwin Bay and Indian Bay were ice-free for most of every winter from 1972-1975. At all of these stations the spring period of increasing temperatures preceded that observed at stations that received winter ice cover. This factor contributed significantly to the accumulation of a greater number of degree-days at both the surface and the substrate at the stations of Kapasiwin Bay and Indian Bay.

Stations near the Wabamun discharge were more strongly affected by thermal effluent than were stations located near the Sundance discharge. This difference was most noticeable with regard to surface temperatures. The lower power output of the Sundance power station during the study interval and the associated lower turnover of cooling water is certainly one reason for this result. Contributing also is the fact that the littoral areas of Indian Bay, which received the Sundance effluent, are much more exposed to wind and wave action than is the area around the Wabamun discharge. This results in a more effective areal dispersion of the heated outflow in the Sundance area.

Temperature studies from the deep-water stations from the western portion of the lake (Stations 17, 18, and 19) indicated that, even in the deepest areas of Lake Wabamun, no thermocline formation occurred. During the warming phase of the season, (May, June, and July), pronounced surface to substrate temperature differentials were present (Figs. 4c to E) and temperature profiles obtained at these stations during late June and the month of July (Figs. 5, 6, and 7) showed that the strongest temperature inflections occurred at a different depth at each station. These inflection points consistently occurred at the deepest point in the water column at Station 19 and at the shallowest point at Station 17, with Station 18 being intermediate in this regard. Therefore, one cannot attribute the vertical temperature differentials to thermocline formation. Rather, the appearance of the temperature profiles, and the positioning of the points of strongest temperature inflection in relation to the substrate, would support the idea that the presence of the colder water in the lower portions of the water column was a result of heat loss to the thick layer of ooze present at the bottom of the lake basin. No oxygen deprivation was ever recorded in these colder portions of the water column.

Figures 4C, D, and E show that fluctuations occurred in the substrate temperatures at these stations during the warming phase of the year. These observations are consistent with the above explanation since the extent to which lower regions of the water column would be cooled by the ooze would be expected to vary considerably and depend on the intensity of vertical mixing.

Heat exchange between the water column and the substrate in lakes has been described by Birge, Juday and March (1928), Neumann (1953), and Lewis (1976), and the topic was discussed by Hutchinson (1957, pp. 504-507). The data available on sediment heat budgets (Hutchinson, 1957, p. 507) suggest that heat exchange between sediments and water is of considerable importance in heat budget calculations for small lakes with mud bottoms, and Lewis (1976, p. 49) notes that conduction of heat into and out of the sediment is very important in determining the progression of temperatures at the surface of the substrate. This, he notes (Lewis, 1976, p. 49), is of considerable importance to the lake benthos and to the process of mineral exchange between sediments and the water column.

Birge, Juday and March (1928) measured temperatures at one meter depth intervals down to 5.0 m within the sediment of Lake Mendota below 8 m of water. They recorded temperatures at the substrate surface during June and July very similar to those recorded at Station 18 during this study, whereas at 1 m depth within the substrate the temperatures were consistently about 5°C lower than those recorded at the substrate surface. Substrate temperatures were shown to fluctuate harmonically throughout the year at all depths within the sediment down to 5.0 m, with the lag with respect to the water temperatures increasing with depth, and the amplitude of the annual cycle decreasing from 21.5°C at the mud-water interface to 1.6°C at 5.0 m within the sediment.

The sediment temperature measurements of Birge, Juday and March (1928) certainly support the idea that heat loss to cooler sediments was responsible for the lag observed in the warming of the bottom water in the deep portions of Lake Wabamun.

By early August (Fig. 8) the temperature profiles at Stations 17, 18, and 19 had become very uniform throughout the water column. The disappearance of the thermal gradient in the lower portions of the water column coincided with the peak in the water column temperature. The initial portion of August, 1974, featured clear skies, hot weather and very strong winds, a combination ideal for heating the lower regions of the water column and making the sediment surface isothermal with the water column. This warming probably did not extend very deeply into the substrate, since during the middle and latter part of August, slight positive temperature gradients were again present at the sediment water interface, an indication that the main mass of the sediment was still considerably cooler than the water column at this time. The data of Birge, Juday and March (1928) from the 8 m station on Lake Mendota indicate that at a depth of 1 m within the sediment the maximum temperature reached was only 17.0°C, and that this peak was reached about two weeks after the peak temperatures (22.5°C) were recorded at the substrate surface. Furthermore, at this station in Lake Mendota the sediment continued to cool the water column until temperatures had dropped below 15.0°C at the sediment surface. From this point onwards the sediments were consistently warmer than the water column.

This pronounced lag in the cooling of the sediments during autumn was also very evident in Lake Wabamun. Reversed temperature gradients (warm water or sediment below cooler water) at the sediment-water interface became frequent (Figs. 9, 10, and 11) during September and October as temperatures in the water column dropped below 14°C. The magnitude of these reversed temperature gradients was observed to be markedly less than the magnitude of the positive temperature gradients encountered in the lower portions of the water column during the warming phase of the year. This is certainly reasonable since convective forces tend to abolish a reversed temperature gradient and to enhance a positive one. The fact that such reversed temperature gradients are present at all, coupled with the observation that they sometimes extend a slight distance upward from the sediment into the water column is likely due to the fact that they are being stabilized by a chemocline near the sediment-water interface. Unpublished data (Gallup and Rasmussen) from Pigeon Lake, Alberta, a lake very similar to Lake Wabamun, show that at the sediment-water interface the conductivity measured was consistently

10% to 15% higher than that measured throughout the water column. Lewis (1976) also concluded that such reversed temperature gradients were being maintained by chemoclines near the sediment in Par Pond and in Pond B, South Carolina.

The return flow of heat from the sediments continued throughout the winter and was probably a significant factor in the gradual rise of the water temperatures under the ice in Lake Wabamun throughout the course of the winter. Winter heating under ice cover has been described by several authors including Birge, Juday and March (1928), Langmuir (1938) and others, and the topic was discussed by Hutchinson (1957, p. 454). This phenomenon has been attributed to two main causes; firstly solar radiation entering ice and thereby heating the water beneath it, and secondly, heat flow from the sediments. By calculating heat budgets for both water and sediments, Birge, Juday and March (1928) estimated that one-fourth of the under-ice heat was derived from the sediments.

Due to the redistribution of the heated water caused by density currents, both sources of heating will result in the deeper portions of the water column being the warmest, as was observed during this study (Fig. 12). The presence of temperatures well in excess of 4.0°C near the sediment at depths of 8.0 m and greater was very likely caused by the flow of solutes from the sediment resulting in a chemocline which permitted the water above 4.0°C to remain at the bottom of the water column. Hutchinson (1957) cites this as a very common cause of this type of irregularity in temperature profiles recorded from under ice.

THE MACROINVERTEBRATE FAUNA OF LAKE WABAMUN AND THE EFFECTS OF HEATED WATER DISCHARGES FROM THE ELECTRIC POWER STATIONS

I. THE MACROINVERTEBRATE SPECIES AND THEIR DISTRIBUTION WITHIN LAKE WABAMUN

A. RESULTS

The collections from Lake Wabamun included 9 species of Oligochaeta, 5 species of Hirudinea, 2 species of Platyhelminthes, 4 species of Pelecypoda, 12 species of Gastropoda, 15 species of Ostracoda, 2 species of Amphipoda, 8 species of Odonata, 7 species of Ephemeroptera, 22 species of Trichoptera, and 109 species of Diptera. Certain groups of animals appeared in the samples but were not identified. These included Hydracarina, Nematoda, Cladocera, and Copepoda. No attempt was made to study the communities of animals present along the margin of the lake, or in the emergent zones which in Lake Wabamun includes a significant amount of *Typha* marsh area.

A systematic account of the species being dealt with is given in Appendix 1, which includes notes on systematics and references many of the prominent papers pertaining to species present within Lake Wabamun. One-hundred-nine species of Diptera are listed within Appendix 1, and 106 of these belong to the family Chironomidae. The subfamily Chironominae was represented by 67 species, of which 44 were of the tribe Chironomini, and 23 were Tanytarsini. The subfamily Orthocladiinae was represented by 25 species, the Diamesinae by 1 species, and the Tanypodinae by 13 species.

Tables 2 to 6 list species recorded at each of the 19 regular sampling stations whose locations are shown in Figure 1. Data are

Table 2

Some macroinvertebrate species of Lake Wabamun and the stations at which each was recorded

(Turbellaria, Oligochaeta, Hirudinea, Pelecypoda, Gastropoda and Amphipoda)

Station #	1				7		2			3				9			13		14	
Year, 19-	72	73	74	75	74	75	72	73	74	72	73	74	75	73	74	75	74	75	74	75
Depth	1.5m				1.5m		1.5m			1.5m				1.5m			1.5m		1.5m	
Turbellaria																				
Dugesia tigrina	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Oligochaeta																				
Tubificidae																				
Limnodrilus hoffmeisteri	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tubifex kessleri	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Naididae																				
Nais pardalis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Nais elinguis (?)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Stylaria lacustris	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Chaetogaster diaphanus	X	X	X	X	X	X	X	X	X											
Chaetogaster crystallinus (?)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pristina sp. #1																	X		X	
Hirudinea																				
Glossophonia complanata	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Marvinmeyeria lucida	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X				
Helobdella stagnalis	X	X	X	X	X	X	X	X	X		X	X	X		X	X		X		X
Erpobdella punctata	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Nephelopsis obscura	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pelecypoda																				
Anodonta grandis	X	X	X	X	X	X											X			
Sphaerium lacustre	X	X			X	X	X	X		X	X	X		X	X	X				
Pisidium casertanum	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pisidium compressum	X																X	X	X	X
Gastropoda																				
Valvata tricarinata	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Valvata sincera		X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lymnaea stagnalis					X						X				X			X		
Lymnaea elodes	X	X																		
Physa gyrina	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gyraulus deflectus	X	X	X	X	X	X	X	X		X	X			X			X		X	
Gyraulus parvus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Armiger crista		X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Promenetus exacuous	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Helisoma anceps	X	X																		X
Helisoma trivolvis							X			X	X			X	X	X	X	X	X	
Crustacea																				
Amphipoda																				
Gammarus lacustris								X	X	X	X	X	X	X	X	X	X	X	X	X
Hyalella azteca	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

4				5				8		10		15		6				16				11	12	17	18	19
72	73	74	75	72	73	74	75	74	75	74	75	74	75	72	73	74	75	72	73	74	75					
3m				2.5m				3m		3m		3m		4.5m				4.5m				4.5m	6m	6m	8m	11m
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						X	X				
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X											
X	X	X	X	X	X	X	X	X	X		X	X			X											
X	X	X	X	X	X	X	X	X	X																	
X	X	X	X																							
X	X	X	X	X	X	X	X	X	X																	
X	X	X	X	X	X	X	X	X	X																	
				X																						
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X					X	X											
		X			X			X	X																	
X		X																								
X	X			X	X	X		X	X																	
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X						
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X												
	X							X																		
X																										
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X				
X	X			X	X	X																				
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X									
	X	X	X	X	X	X	X		X																	
X	X	X	X	X	X	X	X	X	X	X	X		X	X												
				X						X								X								
				X	X	X			X	X	X	X	X													
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

presented for each year that year-around sampling was done at a given station.

Table 2 gives the stations at which various species of Oligochaeta, Hirudinea, Platyhelminthes, and Mollusca were recorded. The distribution of most of these species was found to be centered in the littoral regions of the lake and only a few of them were recorded at depths beyond 4.5 m. Most species recorded from deeper regions were found to be most abundant within the littoral zone.

The naidid oligochaetes were almost always found in samples which contained vegetation, and consequently occurrences of these species beyond 3 m in depth were infrequent. The tubificid oligochaetes on the other hand were found within the sediment at all depths. *Limnodrilus hoffmeisteri* was recorded at depths as great as 8 m, but it was most abundant at the shallow water stations - Stations 1, 4, 7, 13, and 14. *Tubifex kessleri* Brinkhurst and Cook was recorded from all depths, but it reached its greatest abundance at Stations 1 and 4.

The Hirudinea were, in general, confined to depths of 4.5 m or less and their numerical abundance was highest in areas characterized by rich growth of aquatic macrophytes. *Helobdella stagnalis* (Linnaeus) was a definite exception to this pattern since it was recorded from all depths in the lake.

Most molluscs were confined to littoral regions, where they were generally taken in samples which contained vegetation. Both gastropods and pelecypods were found in their greatest abundances upon vegetation near the heated discharges. Among the molluscs, only *Pisidium casertanum* (Poli) was found in sediments from deeper stations including considerable numbers recorded at Station 19 at a depth of 11 m. Stations 13 and 14, which were stations characterized by hard substrates, contained essentially the same molluscan fauna as was recorded over soft substrates. *Pisidium compressum* (Prime) was an exceptional species in this regard, in that it was only common on hard substrates.

Dugesia tigrina was an extremely common species in the littoral zones and it was most abundant upon the thick growths of vegetation at Stations 1, 2, 4, and 7, which were located near the thermal discharges.

Of the groups of animals listed thus far, all were considerably more abundant at stations (1, 2, 4, and 7) which received the greatest thermal input. Only one species from these groups demonstrated any indication that the conditions at these heated stations were unfavorable to it. This species was *Valvata sincera* Say which was only infrequently taken in samples from Stations 1 and 7. Although *V. sincera* was only infrequently found to be as abundant as *V. tricarinata* at littoral stations distant from the heated discharges, it was usually one of the more abundant gastropod species.

The pattern displayed by *Helisoma trivolvis* (Say) also indicates that conditions at the heated stations may be unfavorable for it. Since, however, this species was only rarely encountered at the stations from which it was recorded to be present, it is probably best not to conclude anything from the distribution indicated in Table 2.

Table 3

Some macroinvertebrate species of Lake Wabamun and the stations at which each was recorded

(Ostracoda and non-dipterous Insecta)

Station #	1				7		2			3				9			13		14	
Year, 19-	72	73	74	75	74	75	72	73	74	72	73	74	75	73	74	75	74	75	74	75
Depth	1.5m				1.5m		1.5m			1.5m				1.5m			1.5m		1.5m	
Crustacea																				
Ostracoda																				
Cyprinotus glauca																	X	X	X	X
Cypriconcha barbata															X					
Potamocypris smaragdina	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cyclocypris ampla	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cyclocypris serena							X	X	X	X	X	X	X	X	X	X		X		
Cyclocypris sp. #1																	X	X	X	X
Cypria opthalmica	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Candona candida	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Candona decora	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Candona distincta		X	X		X			X		X	X		X	X		X		X	X	X
Candona rawsoni																	X	X	X	X
Candona ohioensis			X			X				X			X	X		X	X	X	X	X
Limnocythere itasca																	X	X	X	X
Darwinula stevensoni			X																	
Insecta																				
Odonata																				
Tetragoneuria spinigera							X		X	X	X	X	X	X	X	X	X	X		
Aeschna eremita															X					
Lestes sp. #1																	X			
Ischnura sp. #1										X		X		X		X		X		
Enallagma			X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	
Ephemeroptera																				
Caenis simulans	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Leptophlebia pacifica											X			X	X			X		X
Callibaetis coloradensis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Paraleptophlebia sp. #1																			X	X
Trichoptera																				
Polycentropodidae																				
Polycentropus sp. #1													X							
Polycentropus sp. #2		X		X	X	X		X				X				X	X	X	X	X
Neureclipsis bimaculata	X	X	X	X	X	X														
Hydroptilidae																				
Hydroptila albicornis																	X		X	X
Oxyethira sp. #1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Phryganeidae																				
Phryganea cinerea														X	X	X		X		
Agrypnia straminea	X				X	X	X	X		X	X	X		X	X	X	X	X	X	X
Limnephilidae																				
Limnephilus infernalis														X	X	X	X	X	X	X
Molannidae																				
Molanna flavicornis																	X	X	X	X
Leptoceridae																				
Ceraclea sp. #1			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Triaenodes tardu	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Oecetis cinerascens	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Oecetis ochracea																		X	X	X
Oecetis inconspicua																	X	X		X
Oecetis immobilis																	X		X	X
Mystacides interjecta	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lepidostomatidae																				
Lepidostoma sp. #1																		X	X	
Helicopsychidae																				
Helicopsyche borealis																	X	X	X	X

4				5				8		10		15		6				16				11	12	17	18	19
72	73	74	75	72	73	74	75	74	75	74	75	74	75	72	73	74	75	72	73	74	75					
3m				2.5m				3m		3m		3m		4.5m				4.5m				4.5m	6m	6m	8m	11m
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X									
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X				
X	X	X	X	X	X	X	X	X	X	X		X														
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X				
X	X	X	X	X	X	X	X	X	X	X	X	X	X													
		X		X		X	X		X		X	X														
		X					X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
			X		X				X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		X																								
X				X	X	X	X	X	X																	
X		X			X		X		X																	
X	X	X	X	X	X	X	X	X	X	X		X														
X	X	X	X	X	X	X	X	X	X	X	X	X														
X	X	X	X	X	X	X	X	X	X	X	X	X	X													
		X																								
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X						
X	X			X	X		X	X	X	X	X	X														
													X													
X	X	X	X	X	X	X	X	X	X	X	X	X														
X	X	X	X	X	X	X	X	X	X	X	X	X	X													
X	X	X	X	X	X	X	X	X	X	X		X														
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X			X				

Although only two species of Amphipoda are present in the lake, their distributions present an interesting contrast, which, owing to the numerical abundance of these species, is probably quite significant. *Gammarus lacustris* was recorded from stations with depths of 3 m or less. It was, however, absent from Stations 1, 4, and 7 in all years of this study; and at Stations 2, 3, 5, and 8, it was recorded only infrequently and only during the low temperature portion of the year. Successful breeding, including the production and survival of a young cohort was never observed for this species at any of the stations at which even slightly elevated temperatures were observed. *Gammarus lacustris* was observed to breed successfully at Stations 9, 10, 13, 14, and 15.

The distribution of *Hyalella azteca* was strikingly different from that of *Gammarus lacustris*. Although most abundant in littoral regions, *H. azteca* was taken in samples from depths as grest as 8 m, and it was common at a depth of 6 m. At Stations 1, 2, 4, and 7, this species was always present and usually very abundant, and during the summer months, continually breeding.

Table 3 gives the stations at which the species of Ostracoda, Odonata, Ephemeroptera and Trichoptera were recorded. The distribution of the non-dipterous insects was predominantly littoral and few species of any of the groups were recorded from stations whose depth exceeded 3 m. Although the Odonata were, as a group, most abundant upon vegetation at stations of 1.5 m depth, they were extremely rare at Station 13, and only one specimen was ever recorded at Station 14. Both stations have gravel substrates and predominantly low growing vegetation which probably receives a great deal more wave action than does the vegetation from Stations 9 and 3, which grows tall and supports the greatest abundance and diversity of Odonata observed at any station.

Despite the abundance of tall-growing vegetation at stations situated near the thermal discharges, these stations were extremely deficient in odonate species. *Tetragoneuria spinigera* (Selys), the most common anisopteran in the lake, was never recorded from Station 1 or 7, was recorded only once from Station 4, and very infrequently from Station 2, whereas it was recorded at the rate of one to four per sample at Stations 3, 5, 8, and 9.

Ephemeroptera were always found at stations of 3.0 m depth or less. The two species *Caenis simulans* McDunnough and *Callibaetis coloradensis* Banks were widespread and were recorded at all of the littoral stations. *Leptophlebia pacifica* McDunnough was abundant in *Typha* march areas only and was rarely encountered at sampling Stations 3, 9, and 4. *Paraleptophlebia* sp. was found only at Station 14, and only in small numbers and infrequently. I observed this species in large numbers on whitefish eggs, which had been placed on the sand in screen bottomed trays by Ash (1974) in an experiment on egg hatching success. *Paraleptophlebia* sp. was the only species of aquatic invertebrate that had been attracted in large numbers to these egg trays.

Trichoptera were the most diverse group of non-dipterous insects. Most of the species were recorded frequently enough to obtain some idea of their distribution within the lake which was confined to stations of 3.0 m depth or less. Certain of the species were only recorded from Stations 13 and 14, and these are probably restricted to areas characterized by a gravel or sand substrate. *Molanna flavicornis* Banks, *Oecetis ochracea* (Curtis), *Oecetis immobilis* (Hagen), *Oecetis inconspicua* (Walker), *Lepidostoma* sp., and *Helicopsyche borealis* Hagen are of this category, and each of these species have cases constructed of sand. Although *Polycentropus* sp. #2 larvae were found to live upon vegetation at many littoral stations, they were found in their greatest abundance on gravel substrate. Many trichopteran species were found upon vegetation from most of the littoral stations regardless of the nature of the substrate. These widely distributed species included *Oxyethira* sp., *Agrypnia straminea* Hagen, *Ceraclea* sp., *Triaenodes tarda* Milne, *Oecetis cinerascens* (Hagen), and *Mystacides interjecta* (Banks). All of them were recorded at some time from Stations 1, 2, 4, and 7; all except *Oxyethira* sp. and *T. tarda* were recorded at the heated stations much less frequently than they were at Stations 3, 5, 8, and 9; and each, in some years, was not recorded at Station 1. *Oxyethira* sp. and *T. tarda* were often found in large quantities amongst the vegetation near the heated discharges where their growth always appeared to be in advance of that observed for the same species at non-heated stations.

Limnephilus infernalis (Banks) was observed to be locally abundant at Stations 9 and 14, but peculiarly absent from the Kapasiwin and Indian Bay stations. The fact that early instars of this species were only to be found near the shoreline among leaf litter during the month of September could shed some light on the causes for its distribution. The north shoreline of Kapasiwin Bay and the western shoreline of Indian Bay are almost completely devoid of trees and receive little leaf litter. It is possible that female *L. infernalis* restrict their oviposition to areas of shoreline with good tree cover such as is present near Stations 9 and 14.

Neureclipsis bimaculata (L.) was recorded only at Stations 1 and 7. Wiggins (1977) reported this species only from lotic conditions, so it is probable that the slight current near the thermal discharge sites is the factor responsible for the presence of this species.

Stations at which the various species of ostracods were recorded are cited in Table 3. Most were found to be widely distributed within the lake, but three species, *Cyprinotus glauca* Furtos, *Cyclocypris* sp. #1 and *Limnocythere itasca* Cole, were recorded only at Stations 13 and 14, and probably occur only on sand or gravel substrates. Three species were found to be very common upon vegetation. They were *Potamocypris smaragdina* (Vavra), *Cyclocypris ampla* Furtos, and *Cyclocypris serena* (Koch) with the first two named species being by far the most abundant. *P. smaragdina* and *C. ampla* were generally found in great numbers upon vegetation at Stations 1 and 7, but *C. serena* was never recorded from these stations. Two species of the genus *Candona, C. rawsoni* Tressler and *C. ohioensis* Furtos, although recorded from all depths were only infrequently recorded at stations of 3.0 m depth or less, except at Stations 13 and 14 where they were among the most common of the ostracods. At depths of 4.5 m and greater, they were the most common ostracod species encountered. In most mud-bottomed littoral regions (Stations 1, 2, 3, 4, 5, 7, 8, 9, 10, and 15) *Candona candida* (Mueller), *Candona decora* Furtos, and *Cypria opthalmica* (Jurine) were much more abundant than *C. ohioensis* and *C. rawsoni* within the sediments. All three species were recorded at all stations located near the thermal discharge sites, but they were never found during July or August when temperatures at these stations were highest.

Darwinula stevensoni Brady and Robertson and *Cypriconcha barbata* (Forbes) were infrequently found and little can be inferred concerning their distribution or their tolerance of conditions near the thermal discharge sites.

Table 4 lists the species of Orthocladiinae and Diamesinae recorded from the 19 regularly sampled stations. No specimens of these chironomid subfamilies were ever found in samples which did not contain vegetation, and none were recorded from depths in excess of 3.0 m. Many species listed in Table 4 were recorded from only very few stations. It is likely that in certain cases this is more a reflection of the rarity of the species than of very precise habitat requirements.

Five species were recorded only from Stations 13 or 14. These were *Cricoptopus (C.)* sp. #2, *Heterotrissocladius* sp., *Thienemanniella* sp. #1, *Parakiefferella* cf. *torulata* Saether, and *Potthastia* cf. *longimanus* Kieffer. Of these only *Cricotopus (C.)* sp. #2 was abundant. This species was found in large numbers among the roots of *Potamogeton vaginatus* which grew in sand.

Table 4

Some macroinvertebrate species of Lake Wabamun and the stations at which each was recorded

(Orthocladiinae and Diamesinae)

Station #	1				7		2			3				9			13		14	
Year, 19-	72	73	74	75	74	75	72	73	74	72	73	74	75	73	74	75	74	75	74	75
Depth	1.5m				1.5m		1.5m			1.5m				1.5m			1.5m		1.5m	
Diptera																				
Chironomidae																				
Diamesinae																				
Potthastia cf. *longimanus*																	X	X	X	X
Orthocladiinae																				
Acricotopus sp. #1								X	X			X	X	X	X	X		X		
Corynoneura sp. #1									X			X	X	X	X	X	X	X	X	X
Cricotopus (Cricotopus)																				
Cricotopus (C.) sp. #1												X		X	X	X		X		
Cricotopus (C.) sp. #2																	X	X	X	X
Cricotopus (Icocladius)																				
Cricotopus (I.) sp. #2		X	X	X		X	X	X	X	X	X	X	X	X	X	X				
Cricotopus (I.) sp. #3			X		X				X		X	X	X		X					
Cricotopus (I.) sp. #4				X		X		X	X			X	X	X		X	X			
Cricotopus (I.) sp. #5													X			X		X	X	
Cricotopus (I.) sp. #6													X							X
Cricotopus (I.) sp. #7															X					
Heterotrissocladius sp. #1																			X	X
Orthocladius obumbratus														X		X				
Nanocladius cf. *rectinervis*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Parakiefferella cf. *torulata*																	X	X	X	X
Psectrocladius																				
Psectrocladius sp. #1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Psectrocladius sp. #2		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Psectrocladius sp. #3									X			X	X	X	X	X				
Psectrocladius sp. #4															X					
Psectrocladius sp. #6														X	X	X				
Thienemanniella sp. #1																	X	X	X	X
Thienemanniella sp. #2																X				
Zalutschia lingulata												X		X	X	X				

4				5				8		10		15		6				16				11	12	17	18	19
72	73	74	75	72	73	74	75	74	75	74	75	74	75	72	73	74	75	72	73	74	75					
3m				2.5m				3m		3m		3m		4.5m				4.5m				4.5m	6m	6m	8m	11m
	X	X X	X			X	X																			
	X X X	X X X	X X X	X	X X X	X X X	X X X	X	X X	X	X X		X													
X	X	X	X	X	X	X	X	X	X		X	X														
X	X X	X X X	X X	X	X X	X X	X X	X	X	X	X	X														

Species most frequently recorded upon vegetation from mud-bottomed stations were *Acricotopus* sp., *Cricotopus (I.)* sp. #2, *Cricotopus (I.)* sp. #3, *Cricotopus (I.)* sp. #4, *Nanocladius* cf. *rectinerva* (Kieffer), *Psectrocladius* sp. #1, and *Psectrocladius* sp. #2.

Orthoclad species found upon vegetation displayed a consistent and very pronounced cycle of abundance throughout the year. Few of their larvae were ever present among fallen vegetation drawn up from the mud during winter. This observation is consistent with the fact that Orthocladiinae were not found free within the mud at any time. This poor ability to overwinter on fallen vegetation resulted in low populations on the vegetation in spring. Following emergences of these species, larvae rapidly became very abundant upon the vegetation, and by autumn orthoclads made up a significant proportion of the weed-dwelling chironomid fauna.

The only macrophyte species upon which orthoclad larvae were observed to overwinter in proportion to their autumn level of abundance was *Chara globularis* - a species that tends not to deteriorate structurally over the winter and consequently provides the larvae with a refuge from the sediment.

Few orthoclad species were abundant at any time at Stations 1 and 7, and some species, which were normally abundant upon vegetation, were never recorded at these stations. *Nanocladius* cf. *rectinervis*, *Cricotopus (I.)* sp. #2, *Cricotopus (I.)* sp. #3, and *Psectrocladius* sp. #1 were fairly abundant at these stations during spring and winter, but from mid-summer through autumn even these species were rare.

Stations 2 and 4, where the thermal environment was always less extreme than that of Stations 1 and 7, exhibited no deficiencies in abundance or diversity of Orthocladiinae. In fact, due to abundant growths of filamentous algae upon the substrate in the region of the thermal discharge, and the presence of a rich orthoclad fauna within these growths, overwinter survival was enhanced and spring populations of Orthodladiinae were markedly higher there than elsewhere.

Most species of Chironomini (Table 5) were found within the sediment, and were absent from samples containing only vegetation. Stations 13 and 14, where sand and gravel substrate prevailed, had a very distinct assemblage of Chironomini, and several species found there were recorded in mud only infrequently at Station 15, which was located close to the sand at Fallis beach. These species include *Pseudochironomus fulviventris* (Johannsen), *Stictochironomus* sp. #1, *Phaenopsectra jucundus* (Malloch), *Microtendipes* sp. #1, *Dicrotendipes* sp. #2, and *Demicryptochironomus* sp. *Pseudochironomus* sp. #1 was also limited in its occurrence to these two stations, but was usually found within tubes attached to *Chara* and is probably not to be found free within the sediment.

The species composition of Chironomini of mud-bottomed littoral stations varied considerably. At Station 15 (3.0 m), *Chironomus* species were never recorded and the main infaunal Chironomini were *Polypedilum nubeculosum* (Meigen), *Dicrotendipes modestus* (Say), *Parachironomus* sp. #2, and *Cryptochironomus psittacinus* (Meigen). At Station 10 (3.0 m), *Chironomus maturus* (Johannsen) and

Table 5

Some macroinvertebrate species of Lake Wabamun and the stations at which each was recorded

(Chironominae, Chironomini)

Station #	1				7		2			3				9			13		14	
Year, 19-	72	73	74	75	74	75	72	73	74	72	73	74	75	73	74	75	74	75	74	75
Depth	1.5m				1.5m		1.5m			1.5m				1.5m			1.5m		1.5m	
Chironomidae																				
Chironominae																				
Chironomini																				
Chironomus																				
Chironomus sp. #1																				
Chironomus p.-semireductus																				
Chironomus p.-plumosus		X					X	X		X	X									
Chironomus maturus					X		X	X	X	X	X	X	X	X	X	X				
Chironomus anthracinus																				
Chironomus hyperboreus		X	X	X					X											
Chironomus tentans	X	X					X	X												
Chironomus atroviridis	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X				
Chironomus sp. # 2								X	X		X	X	X	X	X	X				
Cryptochironomus psittacinus																		X	X	X
Demicryptochironomus sp. #1																	X	X	X	X
Cladopelma viridula																				
Parachironomus																				
Parachironomus cf. *abortiva*	X	X	X	X	X	X	X	X	X	X	X	X	X		X					
Parachironomus potamogeti	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Parachironomus sp. #1		X	X	X					X											
Parachironomus sp. #2																				
Dicrotendipes																				
Dicrotendipes nervosus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dicrotendipes modestus					X	X	X		X		X		X			X	X			
Dicrotendipes sp. #2																		X	X	X
Dicrotendipes sp. #3	X			X	X	X		X	X		X			X						
Einfeldia																				
Einfeldia pagana		X		X		X	X	X	X	X	X	X	X	X	X	X				
Einfeldia brunneipennis										X		X	X	X		X				
Endochironomus																				
Endochironomus nigricans		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X		
Endochironomus subtendens	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Glyptotendipes																				
Glyptotendipes atrimanus	X	X	X	X		X	X	X	X	X	X	X	X	X		X				
Glyptotendipes paripes																	X		X	X
Microtendipes																				
Microtendipes pedellus								X			X	X	X	X	X	X				
Microtendipes sp. #1																	X	X	X	X
Phaenopsectra jucundus																	X	X	X	X
Stictochironomus sp. #1																	X	X	X	X
Pseudochironomus																				
Pseudochironomus fulviventris																	X	X	X	X
Pseudochironomus sp. #1																	X	X	X	X
Polypedilum																				
Polypedilus nubeculosum																	X		X	X
Polypedilum simulans													X	X	X	X				
Polypedilum sordens															X					
Polypedilum sp. #1											X	X				X				

4				5				8		10		15		6				16				11	12	17	18	19
72	73	74	75	72	73	74	75	74	75	74	75	74	75	72	73	74	75	72	73	74	75					
3m				2.5m				3m		3m		3m		4.5m				4.5m				4.5m	6m	6m	8m	11m
																										X
																	X	X		X		X	X	X		
X	X	X	X	X	X	X	X	X	X					X	X	X	X	X					X	X	X	X
	X	X	X	X	X	X	X	X	X	X	X															
																										X
	X	X	X							X																
X																										
X	X	X	X	X	X	X	X	X	X																	
	X	X	X		X	X	X	X	X	X	X															
X	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
														X		X	X	X	X		X	X	X	X	X	
X	X	X	X		X	X			X																	
X	X	X	X	X	X	X	X	X	X	X		X														
	X	X	X																							
										X	X	X	X				X	X	X	X	X	X	X	X		
X	X	X	X	X	X	X	X	X	X	X	X	X	X													
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
	X		X		X	X		X																		
		X		X	X	X	X	X	X		X															
X		X	X	X	X	X	X	X	X	X	X															
X	X	X	X	X	X	X	X	X	X	X	X	X														
X	X	X	X	X	X	X	X	X		X																
													X													
												X														
												X	X													
		X	X				X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	X				X	X																				

Chironomus sp. #2 were regularly present but not abundant, and *Chironomus hyperboreus* Staeger was recorded occasionally. *Endochironomus nigricans* Johannsen was also present at this station as were *P. nubeculosum, D. modestus, Parachironomus* sp. #2, and *C. psittacinus*.

At Station 8 (3.0 m), *Chironomus* sp. #2 was very abundant and *Chironomus atroviridis* (Townes), *C. maturus,* and *C. plumosus* were also consistently present. *Endochironomus nigricans* and *D. nervosus* (Staeger) were abundant, *D. modestus* was rare and *C. psittacinus* was only recorded once at this station. *Polypedilum nubeculosum* and *Parachironomus* sp. #2 were never recorded from Station 8.

At Station 5 (2.5 m), in 1972 (prior to the onset of macrophyte harvesting), *C. atroviridis* was extremely abundant and *C. plumosus - plumosus* type was also abundant. *Chironomus maturus* was recorded, but only infrequently and in low numbers, while *Chironomus* sp. #2 was absent. *Einfeldia pagana* (Meigen) and *D. nervosus* were abundant, but *E. nigricans* was present only in low numbers. *Dicrotendipes modestus* was very infrequently recorded, and *C. psittacinus, P. nubeculosum* and *Parachironomus* sp. #2 were not found in any of the samples.

At Station 4 (3.0 m), in 1972 (prior to the onset of macrophyte harvesting), *C. plumosus - plumosus* was present in extremely large numbers and outnumbered *C. atroviridis*. *Dicrotendipes nervosus* was present, but *C. maturus* and *Chironomus* sp. #2 were never recorded. A few *Chironomus tentans* Fabricius were found at this station during 1972, and *E. pagana* and *D. nervosus* were also found. Only one specimen of *E. nigricans* was recorded at Station 4 in 1972, and *D. modestus*, *C. psittacinus*, *P. nubeculosum* and *Parachironomus* sp. #2 were absent.

This represents a distinct gradient in species composition from a community whose dominant infaunal Chironomini species was *Polypedilum nubeculosum* to one dominated by *Chironomus plumosus - plumosus* and *Chironomus atroviridis*. An observation which correlated perfectly with this gradient in species composition was that at Station 15 the screened Ekman grabs contained almost no plant litter, and the whole sample could be bottled with room to spare in a 100 ml vial. At Stations 4 or 5 in 1972 some samples contained so much old plant debris that more than one 1 liter bottle was required. Samples from Station 10 were slightly richer in plant debris than those from Station 15, and those from Station 8 occupied from 300 ml to 500 ml.

The 1.5 m stations with mud bottoms were observed to have very different assemblages of infaunal Chironomini than those described for Stations 13 and 14. Stations 2, 3, and 9 were all similar in that *Einfeldia pagana* together with *Chironomus* species made up the bulk of the fauna within the sediment.

At Station 9 *E. pagana* was always the most abundant species and next were *Chironomus* sp. #2 and *C. maturus*. A few *C. atroviridis* were usually present at this station. *Dicrotendipes nervosus*, *E. nigricans* and *Microtendipes pedellus* (de Geer) were also abundant species at this station. *Polypedilum simulans* Townes and *Polypedilum sordens* (Wulp) were present at Station 9.

At Station 3, *E. pagana* was, in all years, the most common species and in 1972, *C. atroviridis* was the next most abundant species with *C. maturus* extremely rare and *Chironomus* sp. #2 absent. *Dicrotendipes nervosus* was very abundant at this station, but *E. nigricans* was not, though it usually was present in the samples. *Microtendipes pedellus*, *P. sordens* and *P. simulans* were not found at this station in 1972.

Station 2, in 1972 (prior to the onset of macrophyte harvesting), was dominated by *C. tentans* and *C. atroviridis*. *Einfeldia pagana* was also abundant and *D. nervosus* was found, but *E. nigricans*, *M. pedellus*, *P. sordens* and *P. simulans* were not.

Very low numbers of sediment-dwelling Chironomini were found at Stations 1 and 7, the stations situated in closest proximity to heated discharges, and the number of species of infaunal Chironomini recorded at these stations was consistently lower than at all other littoral stations. It can be seen from Table 5 that most of the species present were not recorded consistently. Generally, the species present were those that were abundant in surrounding areas. For example, *C. tentans* was frequently encountered at Station 1 during 1972, while it was extremely abundant at nearby Station 2. It was recorded at Station 1 once in 1973, and never since, which was coincident with its disappearance from Station 2. At Station 7 *C. maturus* was recorded in low numbers, while it was simultaneously extremely abundant at Station 8 and throughout the area. *Chironomus atroviridis* was recorded at Station 1 in all years, but usually only a few individuals were caught over an entire year; meanwhile, the species was consistently abundant at surrounding stations.

The same is not true of the weed-dwelling Chironomini at these discharge sites. *Glyptotendipes atrimanus* (Coquillet), *D. nervosus*, *Endochironomus subtendens* (Townes), *Parachironomus* cf. *abortiva* (Malloch), and *Parachironomus potamogeti* were consistently abundant upon the vegetation at Stations 1 and 7. Furthermore, *Parachironomus* cf. *abortiva* and *Parachironomus potamogeti* (Townes) were always more abundant at these two stations than at any others. *Parachironomus* sp. #1 was not found upon the vegetation at Station 1 during 1972, and was never recorded from Station 7, but was very common at Stations 1, 2, and 4 during 1973 to 1975. Another weed-dwelling species of Chironomini, *Polypedilum* sp. #1, was very infrequently recorded from all of the stations for which it is marked present in Table 5.

Few of the Chironomini listed in Table 5 occurred consistently at sublittoral stations. *Dicrotendipes modestus* occurred consistently at Stations 6, 16, and 11, which were stations of 4.5 m depth, but it was never found at 6.0, 8.0, or 11.0 m stations. *Cladopelma viridula* (Fabricius) was found at Stations 6, 11, 16, 17, and 18 (8.0 m) indicating that it is predominantly a sublittoral species. *Polypedilum nubeculosum* and *Cryptochironomus psittacinus* were consistently present at all of the sublittoral stations. *Chironomus plumosus - plumosus* was found at all sublittoral stations but its occurrence was spotty. Invariably, when *C. plumosus - plumosus* was taken in large numbers from a sample, the sample contained a large quantity of plant fragments. Samples rich in plant debris were taken more frequently at Station 18 than at any other station beyond 4.5 m depth. The debris consisted of remains of aquatic macrophytes which drifted out from littoral regions.

Chironomus sp. #1 which was never found at depths less than 9.0 m, was the most common species of Chironomini found at Station 19, where it was present in all years of this study. *Chironomus anthracinus* and *C. plumosus - plumosus* were present at Station 19 as well, but were always less abundant than *Chironomus* sp. #1.

The Tanytarsini (Table 6) include both benthic species and species that occurred only on vegetation. *Paratanytarsus* spp. are weed-dwelling and their occurrence was limited to littoral stations. *Paratanytarsus* sp. #1 and *Paratanytarsus* sp. #2 were found in most samples of vegetation and *Paratanytarsus* sp. #1 was abundant even on vegetation from stations near the discharge sites. *Paratanytarsus* sp. #3, *Paratanytarsus* sp. #4, and *Paratanytarsus* sp. #5 were found on *Chara* mats at Stations 13 and 14.

The remainder of the Tanytarsini from Lake Wabamun are benthic species. *Micropsectra* spp. were found only at stations of 3.0 m depth or less. *Micropsectra* sp. #3 occurred only at Stations 13 and 14, usually within tubes attached to the roots of *Potamogeton vaginatus* which grew in sand. *Micropsectra* sp. #1 and *Micropsectra* sp. #2 were recorded only in mud which contained a fair amount of vegetation. *Micropsectra* sp. #2 was found only at Stations 9 and 3, but *Micropsectra* sp. #1 was present at all mud-bottomed littoral stations except Stations 10 and 15. *Micropsectra* larvae were present in considerable numbers in conjunction with *Chironomus maturus* larvae, but were never abundant in samples containing large numbers of the large *Chironomus* larvae (*C. plumosus - plumosus*, *C. atroviridis* and *C. tentans*).

Table 6

Some macroinvertebrate species of Lake Wabamun and the stations at which each was recorded (Chironominae, Tanytarsini and Tanypodinae)

Station #	1				7		2			3				9			13		14	
Year, 19-	72	73	74	75	74	75	72	73	74	72	73	74	75	73	74	75	74	75	74	75
Depth	1.5m				1.5m		1.5m			1.5m				1.5m			1.5m		1.5m	
Chironomidae																				
Chironominae																				
Tanytarsini																				
Micropsectra																				
***Micropsectra* sp. #1**			X			X		X	X		X	X	X	X	X	X				
***Micropsectra* sp. #2**											X			X	X	X				
***Micropsectra* sp. #3**																	X	X	X	X
Paratanytarsus																				
***Paratanytarsus* sp. #1**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
***Paratanytarsus* sp. #2**									X			X	X	X	X	X				X
***Paratanytarsus* sp. #3**																	X		X	X
***Paratanytarsus* sp. #4**																				X
***Paratanytarsus* sp. #5**																	X		X	X
Cladotanytarsus																				
***Cladotanytarsus* sp. #1**																				
***Cladotanytarsus* sp. #2**																	X	X	X	X
***Cladotanytarsus* sp. #3**																				
***Cladotanytarsus* sp. #4**																			X	X
Tanytarsus																				
***Tanytarsus* sp. #1 (cf. *zanthus*)**																				
***Tanytarsus* sp. #2 (cf. *lestagei*)**																				
***Tanytarsus* sp. #3**																	X		X	
***Tanytarsus* sp. #4**																				X
***Tanytarsus* sp. #5**																				
***Tanytarsus* sp. #6**																				
***Tanytarsus* sp. #7**																				
***Tanytarsus* sp. #8**																				
***Tanytarsus* sp. #9**																				
Tanytarsini sp. #1																	X	X	X	X
Tanypodinae																				
Tanypus stellatus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Procladius (Psilotanypus)																				
Procladius bellus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Procladius (Procladius)																				
Procladius denticulatus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Procladius freemani		X		X		X		X	X	X	X		X		X			X	X	X
***Procladius* sp. #1**																	X			X
Procladius ruris																				
***Clinotanypus* sp. #1**												X		X						X
***Thienemannimyia (?)* sp. #1**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Labrundinia pilosella		X		X	X			X		X	X		X	X		X	X		X	
Ablabesmyia																				
Ablabesmyia peleensis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ablabesmyia basalis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
***Ablabesmyia* sp. #1**		X				X			X						X					

4				5				8		10		15		6				16				11	12	17	18	19
72	73	74	75	72	73	74	75	74	75	74	75	74	75	72	73	74	75	72	73	74	75					
3m				2.5m				3m		3m		3m		4.5m				4.5m				4.5m	6m	6m	8m	11m
	X		X			X	X	X	X																	
X	X	X	X	X	X	X	X	X	X	X	X		X													
	X	X	X			X	X		X																	
		X	X							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
			X							X	X	X	X	X	X	X	X	X	X	X	X	X				
												X		X	X	X	X	X	X	X	X	X	X	X	X	X
										X	X	X	X	X	X	X	X	X	X	X	X	X	X			
																X	X		X		X		X			
			X								X	X	X	X		X	X	X	X	X	X	X				
			X							X	X	X	X					X								
																	X									
																						X				
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	X		X		X	X			X	X		X			X	X		X	X		X		X			
		X									X		X	X	X	X	X	X	X	X	X	X	X		X	
X	X	X	X	X	X	X	X	X	X	X	X		X													
	X	X	X	X	X	X	X	X	X		X															
X	X	X	X	X	X	X	X	X	X	X	X	X	X			X										
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X									
			X					X																		

Cladotanytarsus spp. were present within the sediments at both littoral and sublittoral stations. *Cladotanytarsus* sp. #2 and *Cladotanytarsus* sp. #4 were taken only at Stations 13 or 14, whereas *Cladotanytarsus* sp. #1 and *Cladotanytarsus* sp. #3 occurred only in mud and were most abundant at Stations 10 and 15 (3.0 m) and Stations 6, 11, and 16 (4.5 m). *Cladotanytarsus* sp. #1 was recorded from Stations 12 and 17 (6.0 m) and Station 18 (8.0 m) as well, but in much lower numbers. *Cladotanytarsus* larvae were abundant only at stations that featured moderate or low numbers of the *Chironomus* larvae.

Tanytarsus spp. occurred in both littoral and sublittoral sediments. *Tanytarsus* sp. #3 was found only at Stations 13 and 14, and *Tanytarsus* sp. #4 was found only at Station 14. Both were rare. At the 3.0 m stations which contained *Cladotanytarsus* larvae, *Tanytarsus* were also present, but *Cladotanytarsus* always exceeded *Tanytarsus* in abundance. Six *Tanytarsus* spp. were taken at 3.0 m, and of these, most specimens were taken at Stations 10 and 15. Two species of *Tanytarsus* were recorded at Station 4 in 1975. The appearance of *Tanytarsus* and *Cladotanytarsus* at Station 4 accompanied declining populations of large *Chironomus* larvae and this correlates well with the fact that both genera of Tanytarsini were abundant at Stations 10 and 15.

Tanytarsus larvae were numerous at Stations 6, 11, and 16 (4.5 m) and at Stations 12 and 17 (6.0 m). Seven species were taken at 4.5 m and four species were recorded at 6.0 m. Two species of *Tanytarsus* were recorded from Station 18 (8.0 m), but only *Tanytarsus* sp. #2 was found in samples from Station 19 (11.0 m). At all depths the presence of large numbers of *Tanytarsus* larvae in samples always accompanied low numbers of large *Chironomus* larvae.

All genera of the subfamily Tanypodinae (Table 6) except *Procladius* were found mainly within the littoral zone. *Tanypus stellatus* Coquillet was a very common species within the sediment and it was recorded at all stations featuring depths of 4.5 m or less, but was never taken in samples which contained only vegetation. The species of Pentaneurini were all found in association with vegetation and most records were from stations featuring depths of 3.0 m or less. With the exception of *Ablabesmyia* sp. #1, which was never common at any station, the species of Pentaneurini were very numerous upon the vegetation taken at the stations near to the discharge sites.

Procladius spp. were present in both littoral and sublittoral regions of the lake, and some species were taken at every station. *Procladius bellus* (Loew) is predominantly a species of the littoral zone, but it was recorded down to 6.0 m in depth (Station 12). This species was common on vegetation, but it was also numerous in samples which contained no living vegetation. *Procladius denticulatus* Sublette was abundant in sediment samples from littoral stations and at all of the deeper stations as well. *Procladius freemani* Sublette was not as consistently recorded from sediment at littoral stations, but it was regularly taken at depths from 4.5 m down to 11.0 m.

Procladius bellus and *P. denticulatus* were quite abundant at stations situated near the discharge sites for thermal effluent, and *P. freemani* was recorded there as well, but not consistently.

Although *Procladius ruris* Roback was never as abundant as *P. denticulatus* it was taken regularly at depths of 4.5 m to 8.0 m. This species was also recorded at Stations 4, 10, and 15 (3.0 m), but only occasionally. *Procladius* sp. #1 was found at all depths from 1.5 m to 6.0 m, but Table 6 indicates its distribution to be patchy. This species was quite rare and it is probable that its distribution is actually as broad as that observed for the other *Procladius* species.

B. DISCUSSION

The overall character of the macroinvertebrate fauna found within Lake Wabamun during this study is similar in many respects to that described for some other eutrophic lakes of the north temperate zone. The detailed lists of macroinvertebrates published by Berg (1938) from Lake Esrom, Denmark, the community descriptions of Macan (1970, Ch. 10 and 1974, Ch. 3) from the lakes of the English Lake District, and the communities of weed-dwelling macroinvertebrates described by Müller-Libenau (1956) from the lakes of Holstein, Germany, show many similarities at the family and the generic levels to the fauna of Lake Wabamun. The relative numbers of species belonging to the various higher taxa appear to be generally quite similar in all of these localities, and many of the common and abundant species found within Lake Wabamun are actually circumpolar in distribution.

A detailed comparative discussion on macroinvertebrate communities would, at this time, generate far more questions than answers because of the instability and the number of unknowns in systematics and biogeography, together with the paucity of complete, or semi-complete, species lists in the published literature. This assessment is in agreement with that of Macan (1974, Ch. 1) who put forward the view that the time is not yet ripe for a comprehensive analysis of freshwater communities, owing to the vast deficiencies present in our basic knowledge of the species involved.

Analysis of the chironomid fauna according to the percentage of species belonging to the Tanypodinae, the Orthocladiinae+Diamesinae, the Tanytarsini, and the Chironomini (Table 7) has been documented for a number of lacustrine situations. Thienemann (1954) summarized and reviewed much of this information.

Eutrophic lakes can be distinguished from oligotrophic lakes by the predominance of the Chironomini species in the former, and of the orthoclad species in the latter. Chironomini made up 41.5% of the chironomid species of Lake Wabamun, and this value is within the range of values for the eutrophic lakes listed in Table 7 (33.7% - 56.2%) and outside the range of values for the oligotrophic lakes (23.7% - 37.6%). The Orthocladiinae+Diamesinae made up 24.5% of the chironomid species found in Lake Wabamun, and this figure is within the range of values for the eutrophic lakes of Table 7 (9.4% - 27.9%) and outside the range of values for the oligotrophic lakes (24.8% - 43.6%). The percentage contribution from species of the Tanypodinae and the Tanytarsini was fairly uniform over the whole range of lake types, and the contribution from these two groups to the chironomid fauna of Lake Wabamun (Table 7) was within the range of values obtained by other authors.

Table 7

Percentage breakdown of the chironomid fauna for several lakes from Europe and North America

Oligotrophic lakes	Lunzer Untersee (Austria)		Innaren (Sweden)		lakes of Swedish Lappland		Skåren (Sweden)		Ranges (%)
	# spp.	%	# spp.	%	# spp.	%	# spp.	%	
Tanypodinae	12	15.8	23	16.3	20	15.0	6	10.7	10.7 - 16.3
Orthocladiinae + Diamesinae	29	38.2	35	24.8	58	43.6	17	30.4	24.8 - 43.6
Tanytarsini	17	22.4	30	21.3	23	17.3	19	33.9	17.3 - 33.9
Chironomini	18	23.7	53	37.6	32	24.7	14	25.0	23.7 - 37.6
Total No. of species	76	100.0	141	100.0	133	100.0	56	100.0	
Reference	Thienemann (1950, 1954)		Brundin (1949)		Brundin (1949)		Brundin (1949)		

Eutrophic lakes	Grosser Plöner See (Germany)		Vaxjosjön (Sweden)		Ringsjön (Sweden)		Chataugua Lake (U.S.A.)		Lake Wabamun (Alberta)		Ranges (%)
	# spp.	%	# spp.	%	# spp.	%	# spp.	%	# spp.	%	
Tanypodinae	14	16.3	9	17.7	7	12.5	11	17.2	13	12.2	12.2 - 17.7
Orthocladiinae + Diamesinae	24	27.9	9	17.7	14	25.0	6	9.4	26	24.5	9.4 - 27.9
Tanytarsini	19	22.1	5	9.8	10	17.9	11	17.2	23	21.7	9.8 - 22.1
Chironomini	29	33.7	28	54.9	25	44.6	36	56.2	43	41.5	33.7 - 56.2
Total No. of species	86	100.0	51	100.0	56	100.0	64	100.0	106	100.0	
Reference	Humphries (1938)		Brundin (1949)		Brundin (1949)		Townes (1938)		This study		

Dystrophic lakes	Skarshultsjön (Sweden)		Grimsgöl (Sweden)		Costello Lake (Ontario)		Marion Lake (B.C.)		Ranges (%)
	# spp.	%	# spp.	%	# spp.	%	# spp.	%	
Tanypodinae	6	6.7	10	27.0	6	8.6	13	25.0	6.7 - 27.0
Orthocladiinae + Diamesinae	18	20.2	10	27.0	12	17.1	14	26.9	17.1 - 27.0
Tanytarsini	22	24.8	3	8.1	17	24.3	9	17.3	8.1 - 24.8
Chironomini	43	48.3	14	37.9	35	50.0	16	30.8	30.8 - 50.0
Total No. of species	89	100.0	37	100.0	70	100.0	52	100.0	
Reference	Brundin (1949)		Brundin (1949)		Miller (1938)		Hamilton (1965)		

The benthic chironomid assemblages in Lake Wabamun are also typically eutrophic in their character. Saether (1975) listed species most commonly associated with eutrophy in littoral and sublittoral lacustrine environments, and his list included such species as *Chironomus plumosus - plumosus, C. tentans, C. plumosus - semireductus, polypedilum nubeculosum,* and some *Cladotanytarsus* spp. and *Tanytarsus* spp., which are all important components of the Lake Wabamun benthos.

The plant-dwelling macroinvertebrate fauna of Lake Wabamun is tabulated in Table 8. Comparison of the species listed in Table 8, with the information presented in Tables 2 to 6, shows that most species found in littoral regions of the lake were present upon submerged macrophyte vegetation and were absent from littoral areas that did not contain vegetation. This then shows that the presence of vegetation is the largest single factor responsible for the enormous macroinvertebrate diversity found in the littoral regions of the lake. Figure 14 shows graphically the decline in diversity which occurs at the periphery of the littoral zone.

That the character of the fauna associated with littoral vegetation differs markedly from the benthic lacustrine fauna is well known. Macan (1974), Müller-Libenau (1956), McGaha (1952), Berg (1938), and Berg (1949, 1950) have all described macroinvertebrate fauna, or portions thereof, from lentic situations. All of the above authors reported assemblages very similar in character to that given in Table 8. A comparison of the composition of the vegetation-dwelling chironomid fauna (Table 8) to that of the chironomid fauna

Table 8

Macroinvertebrate species found in samples of vegetation from stations 1, 2, 3, 4, 5, 7, 8, 9, and 15

- Turbellaria
  - *Dugesia tigrina*
  - *Mesostoma* sp.#1
- Oligochaeta
  - Naididae
    - *Nais pardalis*
    - *Nais elinguis*
    - *Stylaria lacustris*
    - *Chaetogaster diaphanus*
    - *Chaetogaster crystallinus*
- Hirudinea
  - *Glossophonia complanata*
  - *Marvinmeyeria lucida*
  - *Helobdella stagnalis*
  - *Erpobdella punctata*
  - *Nephalopsis obscura*
- Pelecypoda
  - *Sphaerium lacustre*
  - *Pisidium casertanum*
- Gastropoda
  - *Valvata tricarinata*
  - *Valvata sincera*
  - *Lymnaea stagnalis*
  - *Lymnaea elodes*
  - *Physa gyrina*
  - *Gyraulus deflectus*
  - *Gyraulus parvus*
  - *Armiger crista*
  - *Promenetus exacuous*
  - *Helisoma anceps*
  - *Helisoma trivolvis*
- Crustacea
  - Amphipoda
    - *Gammarus lacustris*
    - *Hyalella azteca*
  - Ostracoda
    - *Cypriconcha barbata*
    - *Potamocypris smaragdina*
    - *Cyclocypris ampla*
    - *Cyclocypris serena*
- Insecta
  - Odonata
    - *Tetragoneuria spinigera*
    - *Aeschna eremita*
    - *Enallagma* spp.
    - *Ischnura* sp.#1
  - Ephemeroptera
    - *Caenis simulans*
    - *Callibaetis coloradensis*
    - *Leptophlebia pacifica*
- Trichoptera
  - *Triaenodes tarda*
  - *Polycentropus* sp.#1
  - *Polycentropus* sp.#2
  - *Neureclipsis bimaculata*
  - *Hydroptila albicornis*
  - *Oxyethira* sp.#1
  - *Phryganea cinerea*
  - *Agrypnia straminea*
  - *Limnephilus infernalis*
  - *Ceraclea* sp.#1
  - *Oecetis cinerascens*
  - *Mystacides interjecta*
- Diptera
  - Chironomidae
    - Orthocladiinae
      - *Acricotopus* sp.#1
      - *Corynoneura* sp.#1
      - *Cricotopus (C.)* sp.#1
      - *Cricotopus (I.)* sp.#2
      - *Cricotopus (I.)* sp.#3
      - *Cricotopus (I.)* sp.#4
      - *Cricotopus (I.)* sp.#6
      - *Orthocladius obumbratus*
      - *Nanocladius rectinervis*
      - *Psectrocladius* sp.#1
      - *Psectrocladius* sp.#2
      - *Psectrocladius* sp.#3
      - *Psectrocladius* sp.#6
      - *Thienemanniella* sp.#2
      - *Zalutschia lingulata*
      - *Cricotopus (I.) tricinctus*
    - Chironominae
      - Chironomini
        - *Parachironomus abortiva*
        - *Parachironomus potamogeti*
        - *Parachironomus* sp.#1
        - *Dicrotendipes nervosus*
        - *Dicrotendipes* sp.#3
        - *Endochironomus nigricans*
        - *Endochironomus subtendens*
        - *Glyptotendipes atrimanus*
        - *Polypedilum sordens*
        - *Polypedilum* sp.#1
      - Tanytarsini
        - *Paratanytarsus* sp.#1
        - *Paratanytarsus* sp.#2
        - *Micropsectra* sp.#1
    - Tanypodinae
      - *Procladius bellus*
      - *Ablabesmyia peleensis*
      - *Labrundinia pilosella*
      - *Thienemannimyia* ? sp.#1

---

of the lake as a whole (Table 7) is of interest. Orthoclad species made up 47.1%, Chironomini made up 29.4%, Tanytarsini 8.8%, and the Tanypodinae 14.7% of the chironomid species found upon vegetation. In the chironomid fauna of the lake as a whole, Orthocladiinae made up 23.6%, Chironomini 41.5%, Tanytarsini 21.7%, and Tanypodinae 12.2% of the total number of chironomid species. Therefore, the Orthocladiinae, which are completely absent from the Lake Wabamun benthos, contribute almost half of the chironomid species to the vegetation-dwelling fauna; and the Chironominae, which make up most of the lake's benthos, contribute just over one-third of the species to the vegetation-dwelling fauna. This observation is consistent with the fact that orthoclad chironomids are well known to thrive in well oxygenated environments and to be rare to absent in the anoxic muds of eutrophic lakes, where the Chironominae are highly successful (Thienemann, 1954; Brundin, 1951).

II. THE PROMINENT BENTHIC CHIRONOMINAE AND THE EFFECTS OF HEATED EFFLUENTS AND MACROPHYTE HARVESTING ON THEIR DEPTH DISTRIBUTIONS

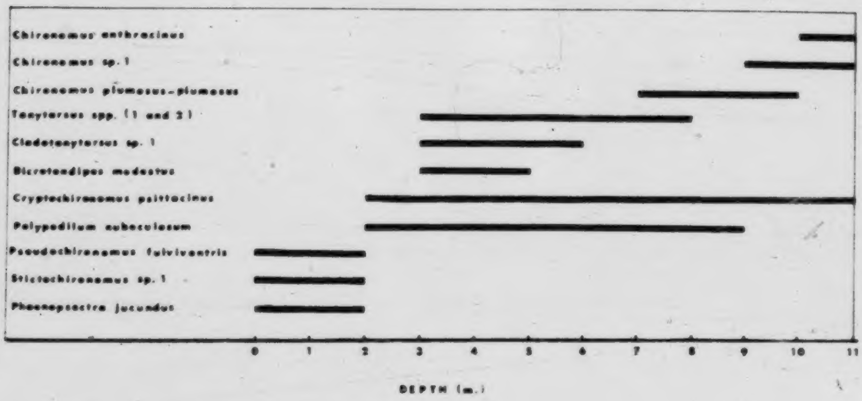
The benthic Chironominae constitute the group of animals which exhibited the greatest diversity of all of the groups studied. The species of this group also displayed the most restricted distributions with respect to depth and substrate type. In the previous section, the distributional data on the Chironominae showed that considerable regional variation in benthic assemblages was present within Lake Wabamun; and that in general, the eastern portion of the lake, especially the areas near the heated discharges, featured different benthic communities from those found in the western portion of the lake. Spatial variation in the assemblages of the benthic Chironominae, and the effects of macrophyte harvesting in the area of the Wabamun discharge on the benthic communities of the area will be examined in this section.

Figure 13 shows the depth distributions of the most prominent Chironominae. These data were obtained from three transects (Fig. 1) from different localities within Lake Wabamun. A species or genus was considered prominent at a given depth if it, at some portion of the season, yielded an estimated average of over 100 mg per 6" Ekman grab (= 4.3 g/m^2).

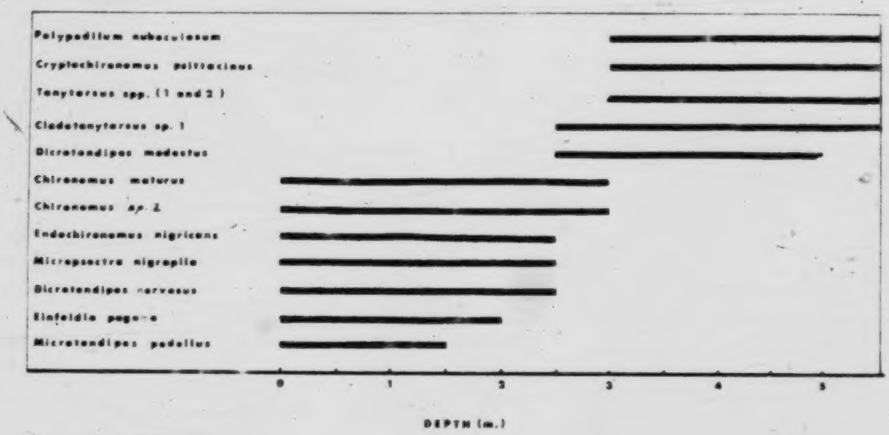
Figure 13A shows the depth distributions for the Fallis transect (Fig. 1). Samples from this transect were taken at 1.0 m depth intervals 5 times during the period from May 3 to September 10, 1975. Stations 14, 15, 16, 17, 18, and 19 were considered to be part of this transect.

The shallow littoral benthic species were those characteristic of sand and gravel substrates, *Phaenopsectra jucundus, Stictochiromonus* sp., and *Pseudochironomus fulviventris.* At about 2.0 m to 2.5 m on this transect the sediment graded into mud and *Polypedilum nubeculosum, Cryptochironomus psittacinus, Cladotanytarsus* sp. #1, *Tanytarsus* spp., and *Dicrotendipes modestus* were prominent species. The *Tanytarsus* spp., *C. psittacinus,* and *P. nubeculosum* were abundant all the way to 8.0 m in depth. Within the depth interval of 7.0 m to 10.0 m, *Chironomus plumosus - plumosus* were found regularly and at 9.0 m to 11.0 m *Chironomus* sp. #1 and *Chironomus anthracinus* accounted for most of the biomass.

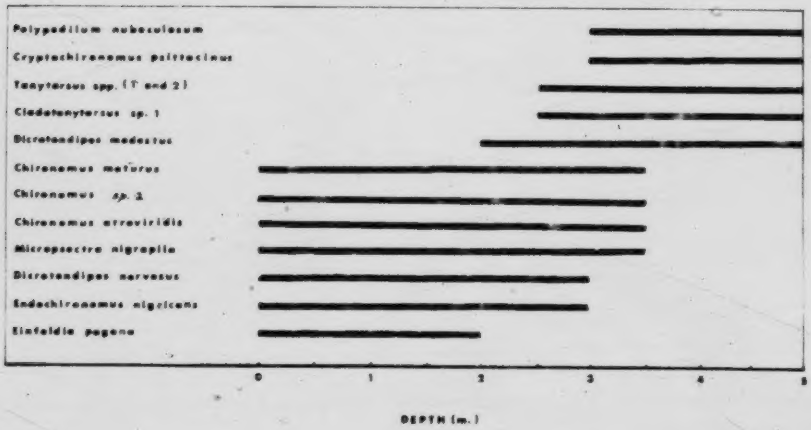
Figure 13. Depth distribution of prominent species of Chironominae for A - the Fallis Transect (T_1) spring and summer, 1975; B - the Wabamun Inlet Transect (T_2) spring and summer, 1974; C - the Kapasiwin Bay Transect (T_3) spring and summer, 1974, and D - the Kapasiwin Bay Transect (T_3) prior to macrophyte harvesting spring and summer, 1972.


Chironomus anthracinus
Chironomus sp. 1
Chironomus plumosus-plumosus
Tanytarsus spp. (1 and 2)
Cladotanytarsus sp. 1
Dicrotendipes modestus
Cryptochironomus psittacinus
Polypedilum nubeculosum
Pseudochironomus fulviventris
Stictochironomus sp. 1
Phaenopsectra jucundus
0
1
2
3
4
5
6
7
8
9
10
11
DEPTH (m.)

A


Polypedilum nubeculosum
Cryptochironomus psittacinus
Tanytarsus spp. (1 and 2)
Cladotanytarsus sp. 1
Dicrotendipes modestus
Chironomus maturus
Chironomus sp. 2
Endochironomus nigricans
Micropsectra nigripila
Dicrotendipes nervosus
Einfeldia pagana
Microtendipes pedellus
0
1
2
3
4
5
DEPTH (m.)

B


Polypedilum nubeculosum
Cryptochironomus psittacinus
Tanytarsus spp. (1 and 2)
Cladotanytarsus sp. 1
Dicrotendipes modestus
Chironomus maturus
Chironomus sp. 2
Chironomus atroviridis
Micropsectra nigripila
Dicrotendipes nervosus
Endochironomus nigricans
Einfeldia pagana
0
1
2
3
4
5
DEPTH (m.)

C

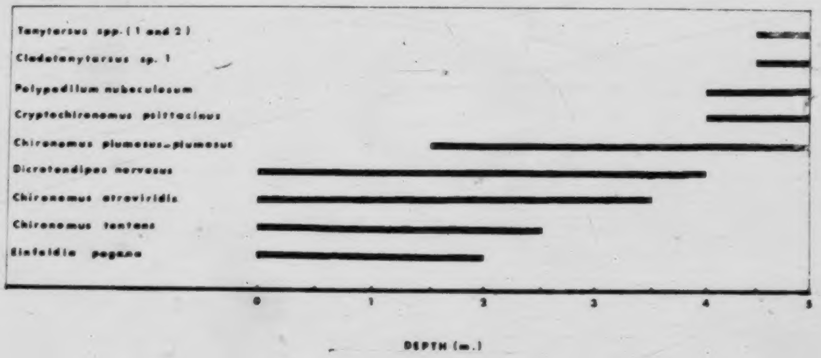

Tanytarsus spp. (1 and 2)
Cladotanytarsus sp. 1
Polypedilum nubeculosum
Cryptochironomus psittacinus
Chironomus plumosus-plumosus
Dicrotendipes nervosus
Chironomus atroviridis
Chironomus tentans
Einfeldia pagana
0
1
2
3
4
5
DEPTH (m.)

Figure 13B shows the depth distributions for the transect from near the intake for the Wabamun power station (Fig. 1). Samples from this transect were taken at 0.5 m depth intervals 4 times between May 6 and September 33, 1974. Stations 9, 10, 11, and 12 were considered to be a part of this transect.

The sediment on this transect consisted of mud at all depths, and up to about 2.5 m this mud was fairly rich in plant debris. At depths less than 3.0 m, *Einfeldia pagana, Microtendipes pedellus, Micropsectra* sp. #1. *Endochironomus nigricans, Chironomus* sp. #2, and *Chironomus maturus* were all very abundant species. From 3.0 m to 6.0 m the mud was practically free of plant debris, and the species composition was practically identical to that found for the same depths in the Fallis transect.

Figures 13C and 13D show depth distributions for the transect from the north shore of Kapasiwin Bay, which began near the Wabamun discharge canal (Fig. 1). Figure 13D shows the species composition and depth distributions found in 1972. Samples from this transect were taken at 0.5 m depth intervals between May 6 and November 10, 1972. Figure 13C shows the species composition and depth distributions for the same transect for 1975. These samples were taken between May 1 and September 10, 1975. Stations 2, 4, and 6 were situated on this transect.

In 1972, before the harvesting of macrophytes had been initiated, the mud at all depths within Kapasiwin Bay was extremely rich in plant debris. Samples from this transect generally occupied from 3 to 5 times as much volume after having been screened as those from the

Wabamun inlet transect of 1974. Among this plant debris were great numbers of large *Chironomus* larvae at all depths, and, as Table 9 indicates, the biomass encountered was extremely high in comparison to that encountered at other localities.

Chironomus tentans was abundant in the mud from shallower regions along with *Einfeldia pagana*. At the intermediate depths *Chironomus atroviridis* and *Chironomus plumosus - plumosus* were most abundant along with *Dicrotendipes nervosus*. Not until depths of 4.0m to 5.0 m were reached did the community begin to resemble that seen at the same depths on the Wabamun inlet or the Fallis transects. Even at these depths, however, *C. plumosus - plumosus* accounted for several times the biomass of *P. nubeculosum*, *C. psittacinus*, *Cladotanytarsus* sp. #1, and *Tanytarsus* species.

The effect of the intensive macrophyte harvesting program on the benthic fauna from Kapasiwin Bay can be evaluated by comparing the 1972 transect with that from 1975. Along with the disappearance of the *C. tentans* larvae from the area, and the reduction in the abundance of *C. plumosus - plumosus* to the point where they occurred only intermittently in the samples, the standing crop of the benthic larvae was drastically reduced, and the sediment contained only slightly more plant debris than that from the Wabamun inlet transect. In addition, *Chironomus atroviridis* occurred at about half of its former abundance, being less abundant than *Chironomus* sp. #2, which was not found in 1972, and *Chironomus maturus*, which had been found only infrequently and in very low numbers in 1972. Furthermore, in the 2 - 5 m depth range the fauna of the Kapasiwin Bay transect had become similar to that observed for the same depth range on the Wabamun inlet transect.

Estimations of standing crop are incomplete and only a few averages can be presented. The data given for some 2.5 m to 3.0 m stations (Table 9) deal only with the results of a few samples taken from the time of year when standing crops were highest at each station. They however indicate the magnitude of differences in standing crop associated with the alteration of the benthic community and the pronounced effect that the removal of vegetation from the Kapasiwin Bay area had on the amounts of benthic faunal biomass present within the sediment.

These observations strongly suggest that the plant litter content of the sediment was a major factor affecting the species composition of the littoral and sublittoral benthic chironomid communities. The *Tanytarsus, Cladotanytarsus,* and *P. nubeculosum* fauna was recorded only at stations where the ooze was free of plant litter fragments, and communities dominated by the large *Chironomus* spp. were found only in areas where the plant litter content of the sediment was extremely high. Furthermore, two smaller *Chironomus* spp. (*C. maturus* and *Chironomus* sp. #2) were found to be dominant at stations where the ooze contained moderate quantities of plant litter. The changes in the benthic chironomid fauna of Kapasiwin Bay, that accompanied the macrophyte harvesting program, also support this idea.

At Stations 2, 3, 4, and 5 the community dominated by the larger *Chironomus* spp. was replaced by one dominated by the smaller species, *C. maturus* and *Chironomus* sp. #2. At Station 6 the community dominated by *C. plumosus - plumosus* was replaced by the *Tanytarsus, Cladotanytarsus,*

Table 9

Standing crop maxima(for the year indicated) for benthic Chironominae from 4 stations of 2.5 - 3.0 m depth.

Standing crop is expressed as grams wet weight per meter^2.

Station 4, 1972 (May 6 - May 18) 4 samples	Station 5, 1972 (May 6 - May 18) 4 samples	Station 10, 1975 (June 10-June 25) 6 samples	Station 15, 1975 (June 10-June 25) 5 samples
122.4 ± 18.5	102.8 ± 16.7	28.5 ± 6.0	17.0 ± 4.5

Station 4, 1975 (May 1-May 15) 5 samples	Station 5, 1975 (May 1-May 15) 5 samples
48.4 ± 11.8	66.3 ± 13.0

The values given are means for the time intervals denoted ± the standard error estimate.

1975 values for Stations 4 and 5 < 1972 values for the same stations at $p < 0.005$ (one-tail Mann-Whitney U-test).

and *P. nubeculosum* assemblage. At all of these stations decreases were noticed in the amounts of plant fragments present within screened sediment samples.

Although *Tanytarsus* spp., *Cladotanytarsus* spp., *Polypedilum nubeculosum*, *Chironomus* sp. #2, *Chironomus tentans*, *Chironomus plumosus - plumosus*, *Chironomus plumosus - semireductus*, and *Chironomus anthracinus* were listed by Saether (1975) as indicators of eutrophy in littoral and sublittoral regions of lakes, the relationship within this group of species and the relationship of the communities present to the presence of macrophyte debris within the sediment has to this point not been studied. *Chironomus atroviridis* and *Chironomus maturus*, which in Lake Wabamun play a very important role, were not listed by Saether (1975). A reference to the importance of decaying plants within the sediment for populations of *Chironomus* spp. was made by Wunder (1949). In his studies of carp rearing ponds and their chironomid populations, he found that *Chironomus thummi* and *Chironomus plumosus* were only present in large numbers in areas where macrophytes were accumulating within the sediment; and that these species were absent, or present in very low numbers, in areas where the sediment was devoid of plant litter.

These results suggest that the widespread abundance of *Chironomus* spp. in the sediments of Kapasiwin and Indian Bays, the areas which received heated effluents from the power stations, was probably not a direct result of slightly higher substrate temperatures but an indirect consequence of the heavy macrophyte populations present in those areas. Macrophytes decaying within the sediments, in combination with their microflora and fauna, would be expected to serve as a nutrient source for the *Chironomus* larvae; and at the same time, the oxygen depletion brought about by the decay process could be a factor rendering the ooze unsuitable for the smaller species such as *Polypedilum nubeculosum*, *Tanytarsus* spp., and *Cladotanytarsus* spp. The relationship between the size of larvae of the Chironominae and their ability to overcome microstratification of oxygen at the sediment-water interface was discussed by Brundin (1951), who concluded that large size was a definite advantage, permitting more efficient tube ventilation under low oxygen conditions.

III. CHANGES IN SPECIES COMPOSITION OF PLANT DWELLING ANIMAL COMMUNITIES FOLLOWING MACROPHYTE HARVESTING IN KAPASIWIN BAY

Besides the previously described alterations in species composition of benthic chironomid communities, many changes occurred in the species composition of the fauna associated with vegetation, most noticeably concerning the chironomid larvae of the subfamily Orthocladiinae (Table 5).

During 1972, samples of vegetation from Stations 1, 2, 3, 4, and 5 yielded very few species of Orthocladiinae. Only *Nanocladius* cf. *rectinervis*, *Psectrocladius* sp. #1, *Psectrocladius* sp. #2, and *Cricotopus(Isocladius)* sp. #2 were found during that year (Table 5) and all were extremely rare at all times. During the summer of 1973 an overall increase in abundance of Orthocladiinae was detected, and as well, several more species were recorded at the Kapasiwin Bay sampling stations. These were *Cricotopus (I.)* sp. #3, *Cricotopus (I.)* sp. #4, and *Acricotopus* sp. In the summers of 1974 and 1975, the third and fourth summers of macrophyte harvesting, Orthocladiinae were abundant among the vegetation and *Psectrocladius* sp. #3, *Corynoneura* sp., *Zalutschia lingulata*, *Cricotopus (I.)* sp. #1, *Cricotopus (I.)* sp. #5, and *Cricotopus (I.)* sp. #6 were recorded in addition to all of those recorded previously.

At all times, Orthocladiinae were numerous and diverse at Station 9 where seventeen species of Orthocladiinae were recorded, including all 13 species that were recorded in Kapasiwin Bay (Table 10). On the other hand, all stations situated within the bays that received thermal effluents had fewer species of Orthocladiinae than observed at Station 9. This difference was most pronounced prior to the harvesting of macrophytes and was to a significant extent abolished in Kapasiwin Bay after two summers of the harvesting operation. The best recovery of the orthoclad fauna was observed at Station 3, which yielded several species otherwise found only at Station 9. Station 3 and Station 9 were similar in that they both supported a rich understory of *Chara*. Species found at Station 3 but nowhere else in Kapasiwin Bay were all found to be living on *Chara*.

Following the harvesting of macrophytes, noticeable changes also occurred within the molluscan community, These changes were, however, in the reverse direction to those described for the Orthocladiinae in that several previously abundant species disappeared from Kapasiwin Bay stations and all species declined in their abundance. *Helisoma anceps* Menke, *Lymnaea elodes* Say, and *Pisidium compressum* were never found

Table 10

The number of species of Orthocladiinae found at stations 1, 2, 3, 4, 5, 7 and 9 during each year of study.

Station #	1972	1973	1974	1975	Total
1	2	4	5	5	6
2	4	6	9	-	9
3	4	5	11	11	13
4	2	7	9	7	9
5	3	6	7	7	7
7	-	-	4	5	6
8	-	-	3	4	4
9	-	12	13	14	17
Total for Kapasiwin Bay	4	7	11	11	13

after 1973 (Table 2) and *Sphaerium lacustre* Müller was recorded only once in 1974 and not at all during 1975.

Agrypnia straminea was the most abundant trichopteran taken during 1972, but from 1973 onwards this species was found very infrequently. Trichopteran species such as *Oxyethira* sp., *Ceraclea* sp., and *Triaenodes tarda* exhibited no decline in their numbers, and were very common in all years.

A. THE ORTHOCLADIINAE AND THEIR RELATIONSHIP TO THERMAL DISCHARGES AND MACROPHYTE REMOVAL

Althouth the benthic chironomid assemblages were mostly characterized by species of the Chironomini and the Tanytarsini, a significant number of species of the Orthocladiinae were present in association with aquatic macrophytes. Most orthoclad species were never taken in large numbers even from the sampling effort which was directed primarily at the examination of vegetation. The presence - absence data derived from the vegetation samples did however indicate that the distribution of the species of Orthocladiinae can provide information concerning the nature of the various littoral habitats.

The presence of a very species-poor and numerically deficient orthoclad fauna in the area of the Wabamun discharge prior to the onset of macrophyte harvesting, and the significant reversal of this situation following the harvesting procedure, is a good indication that decaying aquatic macrophytes, when present in large masses within the sediment, present a poor environment for the overwinter survival of these species. The general observations which have been made on the species of the Orthocladiinae, and their ecological requirements

(Thienemann, 1954; Brundin, 1951) suggest that a high oxygen demand situation, such as is presented when large masses of aquatic macrophytes decay within and upon a largely anoxic sediment, would be highly unfavorable for them. The fact that a marked and general improvement in the overwintering success of the orthoclad species occurred when the macrophyte winter carry-over was reduced, and the fact that these species, during winter, could only be found either on macrophyte vegetation or on filamentous algal material, suggests that a moderate amount of vegetation in association with the sediment provides an optimum overwintering environment.

The richest and most diverse orthoclad fauna at stations that featured ooze sediments was found at Station 9 (Table 10) and at Station 3, following the harvesting of macrophytes. These stations featured the best growth of *Chara globularis* of any of the ooze-bottomed stations. More species and individuals of Orthocladiinae were taken on *Chara* during the winter than from any other overwintering habitat. This certainly supports the notion that a refuge from the sediment during winter facilitates overwintering for at least some orthoclad species. This can be argued from the observation that the *Chara*, though ceasing to grow, does not completely lose its physical integrity and structure during autumn, but rather retains it to a remarkable degree throughout winter. The presence of many Orthocladiinae in samples taken throughout the year from *Scirpus* stems by Klarer (unpublished) also supports this idea.

IV. THE EFFECTS OF THERMAL EFFLUENT AND MACROPHYTE HARVESTING ON THE RELATIONSHIP BETWEEN MACROINVERTEBRATE DIVERSITY AND DEPTH

Owing mainly to the rich diversity of organisms found in association with vegetation, the number of species recorded per station exhibited a sharp drop at the periphery of the zone of plant growth. Table 11 gives values for the total number of species (from the groups tabulated in Tables 2 to 6) collected at each sampling station and also gives the subtotal for each of the major taxa. The 1.5 m stations yielded from 71 to 103 species in total, the 2.5 m to 3.0 m stations yielded totals of 62 to 93 species. From 32 to 44 species were taken at each of the 4.5 m stations, and from 17 to 23 species were taken at the 6.0 m stations. At Station 18 (8.0 m) a total of 16 species were recorded, and at Station 19 (11.0 m) only 13 species were recorded.

From Table 11 it is apparent that stations situated near discharges (Stations 1, 2, 4, and 7) differed markedly from other stations within their depth category with regard to the number of species taken. Stations 1, 2, and 7 yielded fewer species than other stations of 1.5 m depth, and among 3.0 m stations, Stations 4, 5, and 8 yielded more species than Stations 10 and 15. At 4.5 m, Station 6 yielded more species than Stations 11 or 16.

Certain factors, however, militate against direct comparisons among stations using the totals given in Table 11. Firstly, the stations located in Kapasiwin Bay were sampled during more years than were most of the others. Stations 1, 3, 4, 5, and 6 were sampled for 4 years and the totals are therefore accumulations based on more

Table 11

The numbers of species (from the taxa listed in tables 2-6) recorded at each of the sampling stations

Depth	1.5 m							3.0 m		2.5m	3.0 m		4.5 m			6.0 m		8.0 m	11.0 m	Total # of spp. recorded
Station #	1	7	2	3	9	13	14	4	8	5	10	15	6	11	16	12	17	18	19	
Taxon																				
Turbellaria	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1
Oligochaeta	7	7	7	6	6	7	7	7	6	6	4	4	4	2	2	2	2	2	1	8
Hirudinea	5	5	5	5	5	4	4	4	4	5	1	1	2	1	1	1	1	1	1	5
Pelecypoda	4	3	2	2	2	3	2	3	2	2	1	1	1	1	1	1	1	1	1	4
Gastropoda	9	8	8	9	9	9	9	9	7	8	6	5	5	1	3	0	0	0	0	11
Amphipoda	1	1	2	2	2	2	2	1	2	2	2	2	1	1	1	1	1	1	0	2
Ostracoda	8	7	7	9	10	12	11	10	9	10	9	9	6	5	5	3	2	2	2	15
Odonata	1	1	2	3	4	4	1	3	3	3	1	1	0	0	0	0	0	0	0	5
Ephemeroptera	2	2	2	3	4	3	4	2	2	2	2	2	0	0	0	0	0	0	0	4
Trichoptera	8	8	7	8	9	16	15	7	6	6	6	7	2	1	2	0	0	0	0	18
Diamesinae	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Orthocladiinae	6	6	9	13	17	11	9	9	4	7	4	3	0	0	0	0	0	0	0	22
Chironomini	13	11	17	17	17	14	12	19	14	16	13	10	7	7	7	6	6	4	5	36
Tanytarsini	2	2	3	4	4	7	10	7	3	3	6	7	7	7	7	4	2	2	1	22
Tanypodinae	9	9	9	9	10	9	10	11	11	9	10	9	8	5	6	5	2	3	2	12
Total	76	71	81	91	100	103	98	93	75	80	66	62	44	32	36	23	17	16	13	166

years of sampling than the totals presented for most other stations. Secondly, following macrophyte harvesting which began in the summer of 1972, the numbers of species at Stations 1, 2, 3, 4, and 5, which received the treatment, all rose sharply. Therefore comparisons between stations aimed at demonstrating the effects of heated water must take into account the effects of macrophyte harvesting. Table 12 shows the numbers of species obtained for each year of study from the stations where sampling was frequent enough to permit annual estimates.

The number of species increased between 1972 and 1973 at all Kapasiwin Bay stations that underwent mechanical macrophyte harvesting during the summer of 1972. The observation that numbers of species increased after cutting of vegetation at the stations of Kapasiwin Bay was tested against the null hypothesis that numbers of species fluctuated by chance (one-tailed sign test). The one-tailed test is justified since stations which featured moderate amounts of vegetation i.e. similar to that which remained in an area after cutting, always yielded more species than did heavily weeded stations. The probability that the changes were due to chance was < 0.031, if it is assumed that each station represents an independent replicate, and that chance fluctuations in numbers of species recorded would show no directional bias. If Stations 7 and 8, which received some cutting in 1974 are included, the probability estimate is lowered to < 0.01.

It should be noted that the stations of Kapasiwin Bay received cutting and harvesting during the summers of 1973, 1974, and 1975 and that this continued manipulation did not result in a continued increase in the numbers of species recorded. The numbers of species recorded at Station 1 for 1974 and in 1975 were lower than that for 1973, due

Table 12

The numbers of species (from the taxa listed in tables 2 to 6) which were recorded from the stations of 1.5 m - 4.5 m depth, during each year of study.

Depth	Stn.	1972	1973	1974	1975	Total
1.5 m	1	55	66	61	61	76
	7	--	--	62	63	71
	2	63	70	70	--	81
	3	67	74	75	76	91
	9	--	82	82	84	100
	13	--	--	88	89	103
	14	--	--	86	89	98
3.0 m	4	61	71	77	74	93
2.5 m	5	63	70	73	69	80
3.0 m	8	--	--	63	68	75
	10	--	--	57	58	66
	15	--	--	53	50	63
4.5 m	6	37	36	30	36	44
	16	31	27	28	28	36

to the fact that some molluscan species (*Helisoma anceps, Lymnaea elodes, Pisidium compressum*, and *Sphaerium lacustre*) were eliminated from the area. These species were all common in 1972, and in 1973 all were much less abundant. The cutting and removal of vegetation, which was always most intense at this station was probably responsible for the elimination of these species. Decreases in the number of species recorded, though not marked ones, were also recorded for Stations 4 and 5 in 1975. All 1975 values for these stations were still higher than those recorded in 1972.

Because of changes in the numbers of species present, which took place at stations that underwent harvesting, a valid comparison of the numbers of species versus the extent of temperature elevation which took place at these stations cannot properly be done for any given year. In 1972 not enough stations were sampled, and in all subsequent years harvesting in the heated areas, and the changes that this caused, confounded the analysis of the effects of the temperature variable.

However, comparisons involving the numbers of species from heated and unheated stations were drawn in the following manner. For stations that underwent harvesting the analysis was restricted by employing only data obtained prior to and during the first year of harvesting. Changes in species composition were never recorded within the same year that harvesting was initiated. Such data should then be comparable to that obtained from stations that were not harvested. For Stations 1, 2, 3, 4, 5, and 6 the data obtained in 1972 were used, and for the remainder of the stations the 1974 values were used (Table 11).

If the 1.5 m stations featuring mud substrates are compared, they can be ranked as follows with regard to the numbers of species obtained: Station 9 > Station 3 > Station 2 > Station 7 > Station 1. The data for substrate temperatures for spring, summer, and autumn ranked the same stations in the reverse order: Station 1 > Station 7 > Station 2 > Station 3 > Station 9. A statistical argument can be formulated as follows. The number of linear permutations or rankings obtainable from the 5 stations is $5! = 120$, of which only 2 correlate exactly with the ranking obtained from the temperature data, 1 positively and 1 negatively. The permutation obtained by ranking the numbers of species recorded from the 5 stations is exactly negatively correlated with the temperature ranking. The probability of obtaining an exact correlation, by chance, either negative or positive is 2/120 or $p < 0.02$.

The stations of 2.5 m to 3.0 m depth all feature a mud substrate, and none of these underwent more than moderate heating with regard to their substrate temperatures (Table 1). The ranking obtained with respect to substrate temperatures was: Station 4 > Station 5 ≃ Station 8 > Station 10. Station 15 was not studied intensively enough to permit degree-day comparisons with the other stations.

Station 4 yielded 61 species during 1972, Station 5 yielded 63, Station 8, 62 (in 1974), and Station 10 (1974) yielded 57 species. Station 15 yielded 53 species in 1974. It is evident that for these stations no clear ranking relationship between the diversity of the fauna and the substrate temperature is demonstrable. A general relationship does exist however; the stations furthest from the discharge sites yielded fewer species, and the 3 stations situated in the vicinity of the thermal discharge canals yielded nearly identical numbers of species. The differences observed regarding both diversity and temperature among these 2.5 m to 3.0 m stations are of a magnitude much lower than those observed for the 1.5 m stations, where the stations affected by the thermal effluents were situated in much closer proximity to the discharge sites.

At 4.5 m, Station 6, where substrate temperatures were always slightly higher than those at Station 16, yielded consistently more species than the latter station. Here the relationship to temperature is exactly opposite from that observed for the 1.5 m stations, and consistent with that observed for the 2.5 m to 3.0 m stations. Following the harvesting of vegetation from the shallower stations of Kapasiwin Bay, the numbers of species recorded from Station 6 decreased rather than increased as was the case for the other stations. Station 6 was beyond the zone of thick macrophyte growth, and was never subjected to the harvesting procedure, but the cutting from the nearby littoral areas resulted in a marked reduction in the amount of vegetation which accumulated at Station 6 during the autumn and winter. Consequently, it is reasonable that many of the weed-dwelling species which were initially recorded at Station 6 would not be encountered there again.

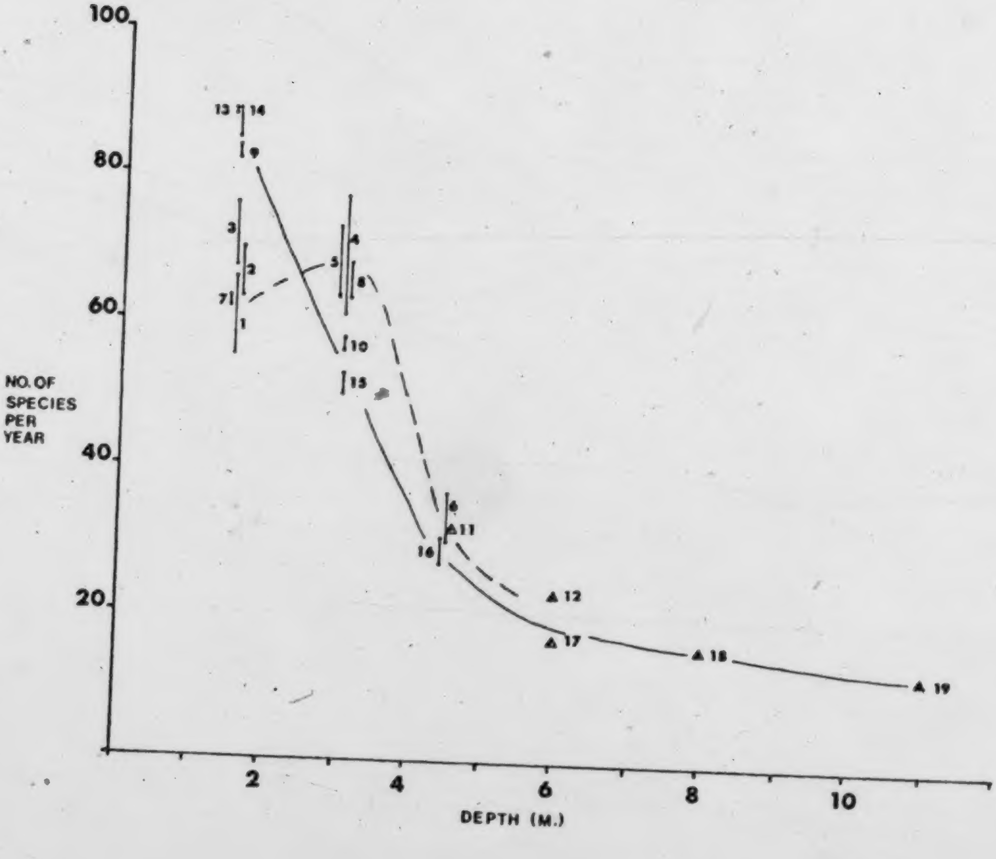
Figure 14 illustrates the relationship between the number of species taken at a station and depth for each of the stations. The stations from which an estimate of the number of species could be obtained for each year of the study are denoted by a range measure, and those for which all data must be presented cumulatively, due to

Figure 14. Number of species vs. depth for heated (dashed line) and non-heated (solid line) stations.

The numbers adjacent to the points or bars are station numbers.

Ɪ indicates the range of values recorded in different years of study.

▲ indicates pooled data for the years 1973-75.


100
80
60
40
20
NO. OF SPECIES PER YEAR
13
14
9
3
2
7
1
5
4
8
10
15
16
6
11
12
17
18
19
2
4
6
8
10
DEPTH (M.)

the lack of sufficient samples to characterize the fauna for any given year, are denoted by the triangles. The two curves are approximate representations of the relationship between diversity and depth for stations distant from the heated discharges (solid line), and the relationship for the stations located in Kapasiwin Bay and Indian Bay which received the heated effluents (dashed line).

The numbers of species recorded at Station 1 and 7 (near the mouths of the discharge canals) were consistently lower than the totals recorded at other stations of the same depth (Tables 11 and 12, Fig. 14). Table 11 shows that not all taxa of macroinvertebrates were equally affected. No deficiencies in the diversity of Oligochaeta, Hirudinea, Pelecypoda, and Gastropoda were evident at Stations 1 and 7. These groups, especially the Tubificidae (Oligochaeta) and the Gastropoda, were more abundant in the heated areas than they were elsewhere. The most notable deficiencies were recorded among the insect taxa, especially Orthocladiinae, Tanytarsini, Chironomini, Ephemeroptera, and Odonata. The substrate temperatures at Stations 1 and 7 were 5°C to 8°C warmer than those recorded at Stations 9 and 14, which were of the same depth (1.5 m), but unaffected by heated water.

Since the thermal effluents at Lake Wabamun were being discharged into very shallow water, no opportunities for studying strongly heated localities of greater depth than 1.5 m were available. Furthermore, the temperature data obtained during this study, and also that reported by Gallup and Hickman (1973, 1975) and by Nuttall (1974), show that the heated waters exhibit a considerable tendency to remain entrained within the top 1 m of the water column. For these reasons, substrate temperatures at the heated stations of 3.0 m depth were always less than 2.0°C above those recorded at Station 10 (3.0 m). The fact that temperature elevation at Stations 4, 5, and 8 was not acute is consistent with the high species totals recorded at these stations. In fact, Stations 4, 5, and 8 always yielded slightly larger numbers of species (Fig. 14) than did Stations 10 and 15 (3.0 m) which were not located near heated discharges. The harvesting of macrophytes, which was only carried out at the heated stations, was accompanied by an increase in the number of species, and therefore enhanced this differential.

The species that contributed to the higher species totals at Stations 4, 5, and 8 were predominantly weed-dwelling forms and belonged mainly to the Gastropoda, Hirudinea, Orthocladiinae, Chironomini, and the Odonata (Table 7). Stations 10 and 15 featured only very sparse macrophyte growth and this was coupled with a poor carry-over of vegetation through the winter period. Stations 4, 5, and 8, even after the onset of macrophyte harvesting, supported dense growth during summer and good carry-over of vegetation through the winter (detailed data on growth rates and winter carry-over of macrophytes in Lake Wabamun were reported by Haag and Gorham, 1977). Consequently, Stations 4, 5, and 8 offered a more suitable habitat for many weed-dwelling species than did Stations 10 and 15, where weeds were often absent.

Although many species that were generally associated with vegetation could occasionally be found beyond the zone of macrophyte growth, Figure 14 shows that the total numbers of species recorded dropped sharply within the depth interval of 3.0 m to 6.0 m. Stations 6, 11, and 16 (4.5 m) did not support macrophyte growth, but they were subjected to some influx of fallen vegetation during the autumn months. Station 6 was located near the Wabamun discharge and its substrate temperatures were up to 1.0°C higher than those recorded at Stations 11 and 16. Station 6 received a much greater influx of vegetation than did Stations 11 and 16, and this would explain the higher species totals (Fig. 14) recorded at Station 6.

Mild to marked reductions in the numbers of macroinvertebrate taxa have been recorded near thermal discharges by several authors (Wiederholm, 1972; Howell and gentry, 1974; Koss *et al.*, 1974). Dense tubificid oligochaete populations in sediments affected by thermal effluents have been reported by Brinkhurst and Jamieson (1971), Wiederholm (1972), and Koss *et al.* (1974). Such results appear to be the rule in thermally affected areas featuring temperature elevations of about 5.0°C or more, such as was the case for Stations 1 and 7 at Lake Wabamun, during my study.

Research pertaining to areas which feature moderate temperature elevations is meagre, but some results obtained from areas peripheral to thermal discharge areas have been reported. Whitehouse (1971), Wiederholm (1972), and Koss *et al.* (1974) reported unusually dense populations of *Chironomus* larvae in bays which receive heated effluents. Similar results were obtained during this study. Figure 13D shows that the sediments within Kapasiwin Bay were dominated by larvae of *C. plumosus - plumosus* and *C. tentans*. These observations may reflect a general tendency towards enhanced zoobenthic productivity in areas subjected to moderate temperature elevation by thermal effluent.

V. THE EFFECTS OF HEATED WATER ON THE SPECIES COMPOSITION OF MACROINVERTEBRATE COMMUNITIES AND THE POSSIBLE MECHANISMS THROUGH WHICH ALTERATIONS TAKE PLACE

The most noticeable impact of temperature elevation on macroinvertebrate populations occurred at Stations 1 and 7 which were situated at the mouths of the Wabamun and the Sundance discharge canals, respectively. At these stations, substrate temperatures were from 5.0°C to 8.0°C higher than those recorded at Station 9, and the macroinvertebrate fauna was relatively poor in species (Fig. 14), and radically altered with regard to the proportions of the major taxa, such as Chironomidae, Tubificidae, and Gastropoda. At all other stations within Lake Wabamun, benthic chironomid larvae far outnumbered tubificid oligochaetes within the sediments; and chironomids considerably outnumbered gastropods upon vegetation. At Stations 1 and 7, both of these relationships were completely reversed. Gallup, Hickman and Rasmussen (1975) gave quantitative comparisons pertaining to these higher taxa, between two areas of Lake Wabamun which corresponded to Stations 1 and 3 of this study.

Enhanced success of the tubificids *Limnodrilus hoffmeisteri* and *Tubifex* spp. in sediments subjected to elevated temperatures has been well documented (Mann, 1958, 1965; Brinkhurst and Jamieson, 1971; Aston, 1973; Koss *et al.*, 1974). Furthermore, high temperatures (25.0°C to 30.0°C) are known not to interfere with their growth and reproduction (Aston, 1968, 1971). Although several *Chironomus* spp. have been reported from sediments whose temperatures greatly exceeded 30.0°C (Walshe, 1948; Thienemann, 1954; Konstantinov, 1958b), indications from the laboratory studies of Konstantinov (1958a, 1958b) are that temperatures in excess of 25°C are above optimun for the growth of most chironomid species. Konstantinov (1958b) reported that this was especially so for young larvae.

Factors other than the direct physiological effect of temperature on the animals would also be expected to favour tubificids and gastropods over chironomid larvae in the areas of Stations 1 and 7. Two factors would be the high rate of oxygen consuming microbial activity and the rapid rate of periphyton growth which are characteristic of areas receiving heated water discharges. Although both tubificid oligochaetes and sediment-dwelling chironomid larvae ingest mixtures of organic matter, inorganic matter, and microflora and fauna, including bacteria (Konstantinov, 1958b; Brinkhurst and Jamieson, 1971), studies by Brinkhurst (1967) and by Brinkhurst and Chua (1969) provide evidence that the bacterial component is of the greatest significance for the oligochaetes. Besides being capable of turning high standing stocks of bacteria into a nutritional advantage, tubificid oligochaetes are also among the organisms most resistant to the anoxia which generally accompanies high bacterial populations (Brinkhurst and Jamieson, 1971). The success of *Chironomus* culture using plant powders of various kinds (Sadler, 1935; Konstantinov, 1958b) and the tendency for chironomid larvae to display strong avoidance reactions to strongly anoxic sediments (Konstantinov, 1958b), would suggest that a lesser degree of involvement by microbial processes would be beneficial to the growth of chironomid larvae.

The fact that predation by large chironomid larvae on tubificids is often observed in situations where the two co-exist, would be expected to contribute to the numerical advantage normally enjoyed by the chironomid larvae over the tubificids.

A rapid rate of periphyton and epiphytic algal growth would likely favour gastropod molluscs over weed-dwelling chironomids. Weed-dwelling chrionomids (with the exception of predaceous forms) generally utilize macrophytes as substrates upon which to erect tubes and carry on filter-feeding activities (Thienemann, 1954). A rapid growth rate of algal epiphytes and periphyton on the macrophyte stems and leaves, such as occurs during summer at Stations 1 and 7, would be expected to favour such grazing animals as gastropods and the algivorous trichopteran *Triaenodes tarda* (Wiggins, 1977), whereas the tube-dwelling chironomid larvae would likely experience adverse effects. Although few definitive physiological data are available on the gastropod species present in Lake Wabamun, it would seem from the field data available (Agersborg, 1932; McMahon, 1975; Sankurathri and Holmes, 1976a) that gastropods are more tolerant of high temperatures than are most chironomid larvae. It would appear then, that both direct and indirect effects of temperature on the macroinvertebrate animals are contributing to the alterations in species composition in evidence at Stations 1 and 7, and in many other areas which receive heated effluents.

Relationships among the amphipods were also altered in areas that received heated discharges. The elimination of *Gammarus lacustris* from the heated portions of the lake, coupled with the success of

Hyalella azteca, was described in section II, page 94. Both physiological data on the tolerance of *G. lacustris* to high temperatures, and a significant amount of zoogeographical data on this species are available. Laboratory experiments conducted by Smith (1973) indicated that long-term reproductive success in *Gammarus lacustris* is reduced at temperatures above 18°C, and that the mortality of this species is very high at temperatures as moderate as 22°C to 24°C. Distributional data for *G. lacustris* were given by Bousfield (1958) for North America, by Sars (1895) for northern Europe, and by Hynes (1955) for the British Isles. All of these data indicate that *G. lacustris* is predominantly a northern species, and that its physiological propensities are cold stenothermic. In Lake Wabamun *G. lacustris* was observed to breed only during spring, which is consistent with data presented by other authors (Hynes, 1955; Bousfield, 1958; Menon, 1966), and would seem to be a necessary consequence of the physiological data presented by Smith.

All of these data, together with the fact that normal summer temperatures in the littoral regions of Lake Wabamun sometimes reach 21°C to 22°C, even in unheated areas, would suggest that *G. lacustris* in Lake Wabamun survives in a temperature regime near to its upper temperature limit. The fact that this species did not produce a successful cohort of young at any of the stations at which even slightly elevated temperatues were recorded and the fact that this species was never recorded at Stations 1 and 7, can be therefore explained on the basis of the known physiological effects of high temperature on this species.

Hyalella azteca is, on the other hand, a eurythermal (Bovee, 1949) species with a broad latitudinal distribution within North America. It can be found from tropical to north temperate regions (Bousfield, 1958) and its northern distribution is limited by its requirement of temperatures of at least 10°C to 15°C for successful growth, development and reproduction (Cooper, 1965; deMarch, 1977). Bovee (1949) found from laboratory studies that *Hyalella* could survive brief exposures to temperatures as high as 39°C, and could survive successfully at temperatures in the neighborhood of 30°C for indefinite periods. The effect of high temperature regimes on fecundity and reproduction has not, however, been investigated for this species. These data on *Hyalella* are consistent with its observed success in the heated areas of Lake Wabamun.

The effects of the thermal discharges were not confined to the stations in most immediate contact with the heated waters (1 and 7), but were to some extent detectable throughout the area that was being maintained free of ice during winter (Stations 2, 3, 4, 5, 6, and 8 in addition to Stations 1 and 7). The effects noted at the stations whose substrate temperatures were only moderately higher than those of control stations (1°C to 2°C) were considerably different from those described for Stations 1 and 7. The macroinvertebrate communities were not found to be markedly deficient in species; and in fact, due to increased winter carry-over of vegetation, the heated stations at 2.5 m to 4.5 m depths displayed consistently higher species totals than did control stations of the same depth (Fig. 14) where vegetation was generally sparse or absent during winter.

The most pronounced difference between the macroinvertebrate fauna of Stations 2, 3, 4, 5, 6, and 8, and those of their respective control stations (9, 10, 15, 11, and 16) lay in the species composition of the benthic chironomid communities. Stations that featured moderate temperature elevation at the substrate in combination with absence of ice-cover during winter all featured benthic communities dominated by large *Chironomus* spp. (*C. plumosus - plumosus*, *C. tentans*, and *C. atroviridis*), whereas control stations featured benthic communities made up of smaller *Chironomus* spp. (*C. maturus* and *Chironomus* sp. #2) or even smaller species such as *Polypedilum nubeculosum*, *Cladotanytarsus* sp. #1, and *Tanytarsus* spp. Furthermore, the stations affected by the heat also displayed higher benthic standing crops than did control stations (Table 9).

Whitehouse (1971), Wiederholm (1972), and Koss *et al.* (1974) also reported unusually dense populations of *Chironomus* larvae in areas of marginal contact with thermal effluents. These observations may reflect a general tendency towards enhanced zoobenthic productivity in areas subjected to moderate temperature elevation by thermal effluent.

Although the data obtained during this study have not been quantitatively analysed to yield estimates of zoobenthic production, the data on the species composition of benthic chironomids (Fig. 13), and the standing crop information shown in Table 9, give a strong indication that littoral sediments in the general vicinity of the Wabamun discharge were much more productive than those at similar depths elsewhere in the lake. The fairly rapid release of nutrients by the chemical and physical decomposition of fallen macrophytes, (Jewell, 1971; Nichols and Keeney, 1973), makes it probable that macrophyte-rich areas within Kapasiwin Bay would support more zoobenthic production than areas which support sparse macrophyte growth.

Several observations have been documented that support the contention that submerged macrophytes, and not phytoplankton, constitute the most significant nutrient source for the benthic chironomids within Kapasiwin Bay. Noton (1973, 1974) found that primary productivity by phytoplankton at his Kapasiwin Bay stations was only slightly higher than that recorded elsewhere in the lake. This finding supported that of Wheelock (1969) who reported no excessive phytoplankton standing crops in the area of the Wabamun discharge. Furthermore, during the present study, the summer-long harvesting and removal of submerged macrophytes from the littoral regions of Kapasiwin Bay was followed by decreases in the zoobenthic standing crop (Table 9) and changes in the species composition of the benthic chironomid communities. The large *Chironomus* larvae declined drastically in their abundance and were replaced by large numbers of smaller *Chironomus* (*C. maturus* and *Chironomus* sp. #2) species and by species such as *Polypedilum nubeculosum*, *Tanytarsus* spp., and *Cladotanytarsus* spp. These changes eliminated to a considerable degree the differences which existed between the benthic chironomid communities of Kapasiwin Bay and those of unheated littoral zones in Lake Wabamun (Fig. 13), and serve as good evidence that nutrients derived from the decay of submerged macrophytes were instrumental in sustaining high zoobenthic production in Kapasiwin Bay.

The observations which indicate that reductions in zoobenthic productivity follow removal of nutrients by macrophyte harvesting, also suggest that enhanced productivity of zoobenthos need not follow directly from temperature elevations, but rather more probably depends on the availability of a nutrient source. The responses of zoobenthic communities to moderate temperature elevations may then most strongly depend on the manner in which primary productivity by aquatic macrophytes and/or by phytoplankton is affected. The situation resulting from the addition of thermal effluent to water bodies could then by expected to vary considerably in accordance with the availability of nutrients for plant or algal growth. Water bodies receiving both nutrient loads, through inputs of domestic sewage for example, and thermal effluent (as described for Vasteras Bay, Lake Malaren by Wiederholm, 1972) would probably display larger and much more widespread increases in productivity than would nutrient-limited water bodies receiving thermal effluent.

Our understanding of factors affecting the responses of biota to thermal effluents is at present minimal. This follows from the limited amount of integrated research which has been carried out in thermal ecology, and also from the capacity of each water body to produce a unique and complex response. A neglected approach, that of *in situ* experimentation, may be a key to vastly increased understanding. During this study, the effects of a manipulative procedure, macrophyte harvesting and removal, on the macroinvertebrate communities of Kapasiwin Bay were documented. This resulted in a considerably enhanced understanding of the factors that affect the macroinvertebrate species composition and of the mechanism through which changes take place in such communities.

SUMMARY

I. TEMPERATURE STUDIES

Temperatures recorded at the stations situated within Kapasiwin Bay and Indian Bay, which received the heated discharges from the Wabamun and Sundance power stations, were higher than those recorded at stations of similar depth elsewhere in the lake. This was the case for substrate as well as surface temperatures (although differentials were more marked at the surface) and for all seasons of the year. Stations influenced by heated effluents were ice-free during the winters of this study.

No evidence of thermocline formation was found at even the deepest portion of Lake Wabamun. Positive temperature differentials between the surface and the substrate were evident at the deeper stations at all times during spring and summer. The magnitude of the differentials was proportional to depth and declined gradually throughout June, July and August. Heat loss to sediments, whose warming phase lagged behind that of the water column, was considered to be the cause of these vertical differentials.

During autumn, reversed temperature gradients were recorded at or near the water-substrate interface. This was attributed to heat flow from sediments, with the gradient being stabilized by a chemocline at the substrate-water interface.

Under-ice temperatures at all but the shallowest stations increased throughout winter, with the temperatures reached by late winter being proportional to depth. At the greatest depths, temperatures well above 4.0°C were recorded at the substrate surface, and this was probably made possible through the presence of a chemocline in the lower portions of the water column. Under-ice temperature increases were believed to have resulted both from return-flow of heat from sediments and from solar radiation entering the ice and heating the water beneath it.

II. THE MACROINVERTEBRATE FAUNA

Species of the family Chironomidae dominated the macroinvertebrate fauna. The total number of macroinvertebrate species declined with increasing depth, with the most marked decline occurring at the periphery of the zone of plant growth (3.5 m - 4.5 m). Species of the tribe Chironomini dominated the benthos at all depths and in total contributed 41.5% of the total number of chironomid species. Species of the subfamily Orthocladiinae were absent from the benthos in areas which featured ooze substrate, but they contributed the majority of the species to the macrophyte-dwelling chironomid community. Orthocladiinae made up 23.6% of the chironomid species found at Lake Wabamun; Tanytarsini made up 21.7%, Tanypodinae 12.2%, and Diamesinae made up 0.9% of the number of chironomid species.

In Lake Wabamun the benthos of the most eutrophic littoral and sublittoral habitats was dominated by large *Chironomus* larvae (*C. plumosus - plumosus*, *C. atroviridis*, and *C. tentans*). The benthos of moderately eutrophic areas was dominated by smaller *Chironomus* spp. (*C. maturus* and *Chironomus* sp. #2) and the least eutrophic sediments supported mainly *Polypedilum nubeculosum*, *Cladotanytarsus* sp. #1, *Tanytarsus* cf. *xanthus*, and *Tanytarsus* cf. *lestagei*. The amount of decomposing macrophyte remains present within the sediment appeared to be the main trophic factor affecting the species composition of the littoral and sublittoral benthos. In the deepest portions of Lake Wabamun (9 m - 11 m), the benthic fauna was dominated by *Chironomus* sp. #1 and *Chironomus anthracinus*.

The bays that received the heated discharges are predominantly littoral in character, and though the pronounced temperature elevation was confined to areas immediate surrounding the heated outlets, most of the sediments within these bays supported extremely rich growth of aquatic macrophytes.

Stations situated at the mouth of each discharge canal yielded fewer species than did other stations of 1.5 m depth. This deficiency in diversity was confined mainly to aquatic insect larvae, although *Gammarus lacustris*, a cold-stenothermic amphipod, was absent or only intermittently present in heated areas. Oligochaeta, Hirudinea, Pelecypoda and Gastropoda were numerous and diverse in the heated areas. The benthic fauna near the discharge outlets was dominated by tubificid oligochaetes rather than by the large *Chironomus* larvae which predominated over most of the area of the heated bays. The macrophytes which grew within the heated bays were well populated with chironomid and other insect larvae, which usually far outnumbered molluscs. In the areas immediately adjacent to the discharge outlets gastropods were the dominant macroinvertebrate group upon the vegetation.

The average depth of water in the bays that received heated water was approximately 3 m. Substrate temperatures at the 3 m stations were found to be only slightly higher than those recorded at a 3 m station situated outside of the heated area. At the 3 m stations at Kapasiwin Bay, the macroinvertebrate fauna was not found to be deficient in species, but rather was found to yield more plant-dwelling macroinvertebrate species than that of 3 m stations situated outside of the heated area.

The benthic community of the heated 3 m stations was dominated by large *Chironomus* spp. and these stations yielded much higher maximum annual standing crops of benthic chironomid larvae than did unheated 3 m stations. The benthic fauna of the unheated 3 m stations was dominated by smaller species of Chironomini (*P. nubeculosum* and *Chironomus* sp. #2) and by Tanytarsini.

Although the number of species recorded at 4.5 m stations was considerably lower than the number recorded at 3 m stations, the effects of the thermal effluent were smiliar. The enhanced trophic status of the sediments within the heated bays was considered to be a consequence of the large quantities of decaying macrophyte remains present within the ooze.

Mechanical macrophyte harvesting, which involved the cutting and removal of plants, was carried out in Kapasiwin Bay during June - August of 1972 - 1975. This was accompanied by an overall reduction in the annual maximum of standing crop for benthic chironomids, plus a considerable decrease in the abundance of large *Chironomus* spp. and a pronounced shift in dominance to smaller *Chironomus* spp. (*C. maturus* and *Chironomus* sp. #2), *P. nubeculosum* and Tanytarsini.

Macrophyte harvesting also strongly affected the composition of the plant-dwelling macroinvertebrate community in the affected areas.

Prior to the onset of harvesting, stations of Kapasiwin Bay had been deficient in species of the Orthocladiinae, compared with the plant-dwelling macroinvertebrate communities from stations outside of the heated area. Within the first two years that harvesting was in effect, larvae of the Orthocladiinae increased sharply in abundance and in diversity. The deficiency of orthoclad species in the area of heaviest macrophyte growth was considered to have resulted from the extreme anoxia generated by decomposition of plant matter within and upon the sediment. The reversal brought on by cutting and removal of vegetation probably resulted from a reduction in oxygen demand at the sediment-water interface. The effect of anoxia upon the Orthocladiinae was probably most pronounced during winter, when erect plants were not present.

LITERATURE CITED

Agersborg, H. P. K. 1932. The relation of temperature to continuous reproduction in a pulmonate snail. Nautilus 45: 121-123.

Allan, J. A. 1954. Memorandum dated Nov. 27, 1954, to Mr. J. D. Stanley, Production Superintendant, Calgary Power Ltd., from J. A. Allan, Consulting Geologist, Edmonton, entitled "Lake Wabamun Development, Vegetation Survey." Consulting report to Calgary Power Ltd.

Allan, J. A., and J. O. G. Sanderson. 1945. Geology of the Red Deer and Rosebud Sheets, Alberta. Res. Council of Alberta Rep. 13.

Allen, E. D. 1973. An ecophysiological study of the effects of thermal discharges on the submerged macrophytes of Lake Wabamun. M.Sc. Thesis, Dept. of Botany, Univ. Alberta, Edmonton.

Allen, E. D., and P. R. Gorham. 1973. Changes in the submerged macrophyte communities of Lake Wabamun as a result of thermal discharges. Proc. Symp. Lakes Western Can. Univ. Alberta Water Resources Center, Edmonton 2: 313-324.

Altman, P. L., and D. S. Dittmer. (Eds.) 1966. Environmental Biology. Fed. Amer. Soc. for Exp. Biology, Bethesda, Md. Pt. IV and V.

Ash, G. R. 1974. The effects of heated water discharges upon Lake Wabamun, Alberta. M.Sc. Thesis, Dept. of Zoology, Univ. Alberta, Edmonton.

Aston, R. J. 1968. The effect of temperature on the life cycle, growth and fecundity of *Branchiura sowerbyi* (Oligochaeta: Tubificidae). J. Zool. (Brit.). 154: 29.

Aston, R. J. 1971. The effects of temperature and dissolved oxygen concentration on reproduction in *Limnodrilus hoffmeisteri* (Claparède) and *Tubifex tubifex* Müller (Oligochaeta: Tubificidae). Symp. on Freshwater Biol. and Electric Generation. Part 2: 161 RD/L/M 312. London, England.

_____. 1973. Field and experimental studies on the effects of a power station on Tubificidae (Oligochaeta: Annelida). Hydrobiologia 42: 225-242.

Barnett, P. R. O., and B. L. S. Hardy. 1969. The effects of temperature on the benthos near the Hunterston generating station, Scotland. Chesapeake Sci. 10: 255-256.

Barton, R. H., E. A. Christiansen, W. D. Kupsch, W. H. Matthews, C. P. Gravenor, and L. A. Bayrock. 1965. Quaternary. *In:* Geological History of Western Canada. Alta. Soc. Petrol. Geol. 1965. pp. 195-200.

Bayrock, L. A., and G. M. Hughes. 1962. Surficial geology of the Edmonton district, Alberta. Res. Council of Alberta. Preliminary Rep. 62-6: 1-40.

Berg, C. O. 1949. Limnological relations of insects to plants of the genus *Potamogeton*. Trans. Amer. Microsc. Soc. 68: 279-291.

_____. 1950. Biology of certain Chironomidae reared from *Potamogeton*. Ecol. Monogr. 20: 83-101.

Berg, K. 1938. Studies on the bottom animals of Esrom Lake. D. Kgl. Danske Vidensk. Selsk, Skrifter. Naturv. og Math. Afd. 9. Raekke. VIII.

Birge, E. A., C. Juday, and H. W. March. 1928. The temperature of the bottom deposits of Lake Mendota: a chapter in the heat exchanges in the lake. Trans. Wis. Acad. Sci., Arts and Lett. 23: 187-231.

Bousfield, E. L. 1958. Fresh-Water Amphipod Crustaceans of Galciated North America. Can. Field Nat. 72: 55-113.

Bovee, E. C. 1949. Studies on the thermal death of *Hyalella azteca* (Saussure). Biol. Bull. (Woods Hole) 96: 123-128.

Boydell, A. N., L. A. Bayrock, and T. H. Reimchen. 1974. Surficial geology of the Rocky Mountain House area, Alberta. Map NTS 83B. Res. Council of Alberta.

Brinkhurst, R. O. 1966. The Tubificidae (Oligochaeta) of polluted water. Verh. Int. Ver. Limnol. 16: 854.

_____. 1967. The distribution of aquatic oligochaeta in Saginaw Bay, Lake Huron. Limnol. Oceanogr. 12: 137.

Brinkhurst, R. O., and K. E. Chua. 1969. A preliminary investigation of some potential nutrient sources by three sympatric tubificid oligochaetes. J. Fish. Res. Board Can. 26: 2659.

Brinkhurst, R. O., and D. G. Cook. 1974. Aquatic earthworms (Annelida: Oligochaeta) in Hart, C. W. Jr., and S. L. H. Fuller (Eds.) Pollution Ecology of Freshwater Invertebrates. Academic Press pp. 143-156.

Brinkhurst, R. O., and B. G. M. Jamieson. 1971. Aquatic Oligochaeta of the World. Oliver and Boyd, Edinburgh.

Brundin, L. 1949. Chironomiden und andere Bodentiere der südschwedischen Urgebirgseen. Ein Beitrag zur Kenntnis der bodenfaunistischen

Charakterzuge schwedischer oliogtropher Seen. Inst. of Freshwater Res., Drottningholm Rep. No. 30.

Brundin, L. 1951. The relation of O_2-microstratification at the mud surface to the ecology of the profundal bottom fauna. Inst. of Freshwater Res., Drottningholm Rep. No. 32: 32-42.

Cairns, J. Jr. 1956. Effects of increased temperature on aquatic organisms. Ind. Wastes 1: 150.

______. 1976. Heated waste-water effects on aquatic ecosystems. Thermal Ecology II. ERDA Symp. series (CONF 756 425) Augusta, Ga. pp. 32-38.

Carlson, V. A. 1966. Bedrock topography and surficial aquifers of the Edmonton district, Alberta. Earth Sci. Reports 66-3, Res. Council of Alberta. 21 pp. 1 Map NTS 83 H.

______. 1971. Bedrock topography of Wabamun Lake Region. Res. Council of Alberta, Map Sheet NTS 82 G.

Cooper, W. E. 1965. Dynamics and production of a natural population of a freshwater amphipod, *Hyalella azteca*. Ecol. Monogr. 35: 377-394.

Corbet, P. S. 1962. A Biology of Dragonflies. Witherby, London.

Coutant, C. C. 1967. Effect of temperature on the development rate of bottom organisms. *In:* Biological Effects of Thermal Discharges, Ann. Rep. Pacific N. W. Lab., U.S. Atomic Energy Comm., Div. Biol. Medicine. pp. 11-12.

______. 1970. Thermal pollution - Biological effects. A review of the literature of 1969. Batelle Memorial Inst. for the U.S. Atomic Energy Comm. BNWL-SA-3255.

Craven, R. E., and B. E. Brown. 1970. Power plant heated discharge water and benthos in Boomer Lake, Payne County, Oklahoma. J. Kans. Ent. Soc. 43: 122-128.

Crosby-Diewold, J. M., and D. K. Krochak. 1975. The first year of investigations into the effect of thermal effluent on the biota of Lake Wabamun. 1974 interim report. A report for Calgary Power Ltd. prepared by Beak Consultants Ltd.

_____. 1976. The second year of investigations into the effect of thermal effluent on the biota of Lake Wabamun. 1975 interim report. A report for Calgary Power Ltd. prepared by Beak Consultants Ltd.

Davies, R. W., and R. P. Everett. 1975. The feeding of four species of freshwater Hirudinoidea in Southern Alberta. Verh. Int. Ver. Limnol. 19: 2816-2827.

de March, B. G. E. 1977. The effects of photoperiod and temperature on the induction and termination of reproductive resting stage in the freshwater amphipod *Hyalella azteca* (Saussure). Can. J. Zool. 55: 1595-1600.

Fischer, J. 1974. Experimentalle Beiträge zur Ökologie von *Chironomus* (Diptera) I. Dormanz bei *Chironomus nuditarsus* and *C. plumosus*. Oecologia 16: 73-95.

Folsom, T. C. 1976. An ecological study of *Dugesia tigrina* (Turbellaria: Tricladida) in Lake Wabamun, Alberta, a thermally enriched lake. M.Sc. Thesis, Dept. of Zoology, Univ. Alberta, Edmonton.

Fritz, P., and H. R. Krouse. 1973. Wabamun Lake past and present. Proc. Symp. Lakes Western Can. Univ. Alberta Water Res. Centre Edmonton 2: 244-257.

Gallup, D. N. and J. B. Rasmussen. unpubl. Provincial lake surveys done in conjunction with Alberta Dept. of Environment.

Gallup, D. N., and M. Hickman. 1973. Temperature and oxygen distribution in the mixing zone of a thermal discharge to Lake Wabamun, Alberta. Proc. Symp. Lakes Western Can. Univ. Alberta Water Res. Centre Edmonton 2: 285-302.

_____. 1975. Effects of the discharge of thermal effluent from a power station on Lake Wabamun, Alberta, Canada. Limnological features. Hydrobiologia 46: 45-69.

Gallup, D. N., M. Hickman, and J. B. Rasmussen. 1975. Effects of thermal effluent and macrophyte harvesting on the benthos of an Alberta lake. Verh. Int. Ver. Limnol. 19: 552-561.

Gallup, D. N., J. B. Rasmussen, and M. Hickman. 1973. Effects of aquatic macrophyte harvesting and herbicide application on the biota of Lake Wabamun, Alberta. Univ. Alberta report submitted to the Alberta Dept. of Environment.

Gallup, D. N., J. Weisgerber, and J. B. Rasmussen. 1977. The limnology of Moose Lake. A report submitted to the Alberta Dept. of Environment.

Gaufin, A. A., and S. Hern. 1971. Laboratory studies on the tolerance of aquatic insects to heated waters. Prog. Dept. Biol. Stat. Univ. Montana, Missoula.

Gibbons, J. W. 1976. Thermal alteration and the enhancement of species population. Thermal Ecology II. ERDA Symp. series (CONF 750 425). Augusta, Ga. pp. 27-31.

Gravenor, C. P. and L. A. Bayrock. 1961. Glacial deposits of Alberta. *In:* Soils in Canada. Roy. Soc. Can. Spec. Publ. No. 3. pp. 33-50.

Gravenor, C. P. and W. D. Kupsch. 1959. Ice-disintegration features in western Canada. Jour. Geol. 67: 48-64.

Green, R. 1972. Geological map of Alberta. Res. Council of Alberta.

Haag, R. W., and P. R. Gorham. 1977. Effects of thermal effluent on standing crop and net production of *Elodea canadensis* and other submerged macrophytes in Lake Wabamun, Alberta. J. Appl. Ecol. 14: 835-852.

Hamilton, A. L. 1965. An analysis of a freshwater benthic community with special reference to the Chironomidae. App. II Taxonomy of the Chironomidae of Marion Lake, British Columbia. Ph.D. Thesis, Univ. British Columbia, Vancouver.

Hickman, M. 1974. Effects of the discharge of thermal effluent on Lake Wabamun, Alberta, Canada - the epipelic and epipsammic algal communities. Hydrobiologia 45: 199-215.

Horkan, J. P. K. 1971. Some ecological effects of thermal pollution in Lake Wabamun, with special reference to the rotifers. M.Sc. Thesis, Dept. of Zoology, Univ. Alberta, Edmonton.

Howell, R. G., and J. B. Gentry. 1974. Effect of thermal effluents from nuclear reactors on species diversity of aquatic insects in J. W. Gibbons and R. R. Swaritz (Eds.) Thermal Ecology. AEC Symp. series (CONF 730 505). Springfield Va.: National Technical Information Service, U.S. Dept. of Commerce.

Humphries, C. F. 1938. The chironomid fauna of the Grosser Plöner See, the relative density of its members and their emergence period. Arch. Hydrobiol. 33: 535-584.

Hutchinson, G. E. 1957. A Treatise on Limnology. Vol. I. Geography, Physics and Chemistry. J. Wiley and Sons, London and New York.

Hynes, H. B. N. 1955. The reproductive cycle of some British freshwater Gammaridae. J. Animal Ecol. 24: 352-387.

Jewell, W. J. 1971. Aquatic weed decay: Dissolved oxygen utilization and nitrogen and phosphorus regeneration. J. Water Poll. Contr. Fed. 43: 1467-1475.

Jonasson, P. M. 1972. Ecology and production of the profundal benthos in relation to phytoplankton in Lake Esrom. Oikos suppl. 14: 1-148.

Klarer, D. M., and M. Hickman. 1975. The effect of thermal effluent upon the standing crop of an epiphytic algal community. Internat. Rev. ges. Hydrobiol.

Klarer, D. M., and M. Hickman. 1975. The effect of thermal effluent upon the standing crop of an epiphytic algal community. Internat. Rev. ges. Hydrobiol.

Klarer, D. M., M. Hickman, and D. N. Gallup. 1973. Modified temperature regimes in the Sundance area of Lake Wabamun, Alberta. Proc. Symp. Lakes Western Can. Univ. Alberta Water Res. Centre Edmonton 2: 270-284.

Konstantinov, A. S. 1958a. Vliyanie temperatury na skorost' rosta i raznitiya lichinok khironomid. Dokl. Akad. Nauk SSSR, 120 No. 6: 1362-1365. (The effect of temperature on growth and development rates of chironomid larvae.)

_____. 1958b. Trudy Saratoodkogo otdela Vniorkh. Transactions of the Saratov Branch of the All-Union Research Institute of the Lake and River Fisheries. Vol. 5: 276-302. (Cultivation of Chironomidae larvae).

Koss, R. W., L. D. Jensen, and R. D. Jones, 1974. Benthic invertebrates, in L. D. Jensen (Ed.) Environmental Responses to thermal discharges from Lake Norman, North Carolina. Electrical Power Research Institute Publ. 10412, Palo Alto, California.

Langmuir, I. 1938. Surface motion of water induced by wind. Science 87: 119-123.

Lewis, W. M. Jr. 1976. Observations on the superficial sediment temperatures of some lakes in the south-eastern United States. Freshwater Biology 6: 49-57.

Lindsay, J. D., W. Odynsky, T. W. Peters, and W. E. Bowser. 1968. Soil survey of the Buck Lake and Wabamun Lake areas. Alberta Soil Survey Rep. No. 24. Univ. Alberta Bull. No. SS-7. Res. Council of Alberta Rep. No. 87.

Lundbeck, J. 1926. Die Bodentierwelt norddeutscher Seen. Arch. Hydrobiol. Suppl. No. 7: 1-473.

_____. 1936. Utersuchungen uber die Bodenbesiedelung der Alpenrandseen. Arch. Hydrobiol. Suppl. No. 10: 207-358.

Macan, T. T. 1970. Biological Studies of the English Lakes. Longman, London.

Mann, K. H. 1965. Heated effluents and their effect on the invertebrate fauna of rivers. Proc. Soc. Wat. Treat. Exam. 14: 45.

MacGaha, Y. J. 1952. The limnological relations of insects to certain aquatic flowering plants. Trans. Amer. Microsc. Soc. 71: 355-381.

McMahon, R. F. 1975. Effects of artificially elevated water temperatures on the growth, reproduction and life cycle of a natural population of *Physa virgata* Gould. Ecology 56: 1167-1175.

Menon, P. S. 1966. Population ecology of *Gammarus lacustris* Sars in Big Island Lake. Ph.D. Thesis, Dept. of Zoology, Univ. Alberta, Edmonton.

Miller, R. B. 1941. A contribution to the ecology of the Chironomidae of Costello Lake, Algonquin Park, Ontario. Univ. Toronto Stud. Biol. Ser. No. 49.

Müller, H. J. 1970. Formen der dormanz bei Insecten. Nova Acta Leopoldina 35: 1-27.

Müller-Libenau, I. 1956. Die Besiedlung der *Potamogeton* - zone östholsteinischer Seen. Arch. Hydrobiol. 52: 470-606.

Muttkowski, R. A. 1918. The fauna of Lake Mendota, a qualitative and quantitative survey with special reference to the insects. Trans. Wis. Acad. of Sci., Arts and Lett. 19: 374-482.

Nebeker, A. V. 1971a. Effect of temperature and different altitudes on the emergence of aquatic insects from a single stream. J. Kans. Ent. Soc. 44: 26-35.

_____. 1971b. Effect of high water temperature on adult emergence of aquatic insects. Water Research 5: 777-783.

Neumann, J. 1953. Energy balance and evaporation from sweetwater lakes of the Jordan Rift. Bull. Res. Coun. Isreal 2: 337-357.

Nichols, D. A., and D. R. Keeney. 1973. Nitrogen and phosphorus release from decaying water milfoil. Hydrobiologia 42: 509-525.

Noton, L. 1973. Preliminary results of a study concerning primary production in Lake Wabamun, Alberta. Proc. Symp. Lakes Western Can. Univ. Alberta Water Res. Centre Edmonton 2: 304-309.

______. 1974. Phytoplankton productivity in Lake Wabamun, Alberta, and the effect of thermal effluent. M.Sc. Thesis, Dept. of Zoology, Univ. Alberta, Edmonton.

Nursall, J. R., and D. N. Gallup. 1971. The responses of the biota of Lake Wabamun, Alberta, to thermal effluent. Proc. of the Int. Symp. on the Identification and Measurement of Environmental Pollutants, Ottawa. pp. 295-304.

Nursall, J. R., J. B. Nuttall, and P. Fritz. 1972. The effect of thermal effluent on Lake Wabamun, Alberta. Verh. Int. Ver. Limnol. 18: 269-277.

Nuttall, J. B. 1974. A current and temperature study at Lake Wabamun, Alberta. A report submitted to the Inland Waters Directorate, Ottawa, Canada.

Odum, E. P., and R. L. Kroodsma. 1976. The power park concept; ameliorating man's disorder with nature's order. Thermal Ecology II. ERDA Symp. series (CONF 750 425). Augusta, Ga. pp. 1-9.

Ozoray, G. F. 1972. Hydrogeology of the Wabamun Lake area, Alberta. Earth Sci. Reports 72-8. Res. Council of Alberta. 19 pp. 1 Map NTS 83 G.

Pearson, G. R. 1969. Coal reserves for strip-mining in the Wabamun Lake District, Alberta. Res. Council of Alberta, Prel. Rep. 59-1.

Radford, D. S., and R. C. B. Hartland-Rowe. 1971. Emergence pattern of some Plecoptera in two mountain streams in Alberta. Can. J. Zool. 49: 657-662.

Rutherford, R. L. 1928. Geology of the area between the North Saskatchewan and McLeod Rivers, Alberta. Res. Council of Alberta Rep. 19.

Sadler, W. O. 1935. Biology of the midge *Chironomus tentans* Fabr. and methods for its propagation. Cornell Univ. Agricult. Exp. Sta., Mem. 173. pp. 1-25.

Saether, O. A. 1975. Nearctic chironomids as indicators of lake typology. Verh. Int. Ver. Limnol. 19: 3127-3133.

_____. 1977. Taxonomic studies on Chironomidae: *Nanocladius*, *Pseudochironomus*, and the *Harnischia* complex. Bull. Fish. Res. Board Can. 196.

Sankurathri, C. S., and J. C. Holmes. 1976a. Effects of thermal effluent on the population dynamics of *Physa gyrina* Say (Mollusca: Gastropoda) at Lake Wabamun, Alberta. Can. J. Zool. 54: 582-590.

_____. 1976b. Effects of thermal effluents on parasites and commensals of *Physa gyrina* Say (Mollusca: Gastropoda) and their interactions at Lake Wabamun, Alberta. Can. J. Zool. 54: 1742-1753.

Sars, G. O. 1895. Crustacea of Norway. Vol. I. Amphipoda. Christiana and Copenhagen, Cammermeyers.

Sawchyn, W. N., and N. S. Church. 1973. The effects of temperature and photoperiod on diapause development in the eggs of four species of Lestes. (Odonata: Zygoptera). Can. J. Zool. 51: 1257-1265.

Sawyer, R. T. 1974. Leeches (Annelida: Hirudinea) in C. W. Hart, Jr. and S. L. H. Fuller (Eds.) Pollution Ecology of Freshwater Invertebrates. Academic Press Inc. pp. 81-142.

Schwartz, F. W., and D. N. Gallup. 1978. Some factors controlling the major ion chemistry of small lakes: examples from the prairie parkland of Canada. Hydrobiologia 58: 65-81.

Sculthorpe, C. D. 1967. The Biology of Aquatic Vascular Plants. Edward Arnold (Publishers) Ltd., London.

Smith, W. E. 1973. Thermal tolerance of two species of *Gammarus*. Trans. Amer. Fish. Soc. 102: 431-433.

Stalker, A. MacS. 1961. Buried valleys in central and southern Alberta. Geol. Surv. Can., Paper 60-32.

Stanley, B. and H. Dobson. 1961. Aquatic plants in Wabamun Lake. Draft of a report of a study done in 1961 for Calgary Power Ltd.

Storr, J. F., and G. Schlenker. 1974. Response of perch and their forage to thermal discharges in Lake Ontario. In Gibbons, J. W., and R. R. Sharitz (Eds.) Thermal Ecology. AEC Symp. series (CONF 730 505). Springfield Va.: National Technical Information Service, U.S. Dept. of Commerce. pp. 363-370.

Taylor, R. S. 1958. Some Pliestocene lakes of northern Alberta and adjacent areas. Edmonton Geol. Soc. Quart., Vol. 2, No. 4.

Thienemann, A. 1925. Die Binnengewässer Mitteleuropas. Eine limnologische Einfuring. Die Binnengewässer 1, Stuttgart.

_____. 1928. Der Sauerstoff im eutrophen und oligotrophen See. Ein Beitrag zur Seetypen lehre. Die Binnengewässer 4.

_____. 1950. Lünzer Chironomiden. Arch. Hydrobiol. Suppl. No. 18: 1-202.

_____. 1954. *Chironomus:* Leben, Verbreitung und wirtschaftliche Bedeutung der Chironomiden. Die Binnengewässer 20.

Townes, H. K. 1938. Studies on the food organisms of fish. A biological survey of the Allegheny and Chemung Watersheds, State of New York Conservation Dept. Biological Survey 1937, No. XII Suppl. to 27th. Ann. Rep. 1937: 162-175.

_____. 1945. The nearctic species of Tendipedini (Diptera: Tendipedidae = Chironomidae). Amer. Midl. Nat. 34: 1-206.

Walshe, B. M. 1948. The oxygen requirements and thermal resistance of chironomid larvae from flowing and from still water. J. Exp. Biol. 25: 35-44.

Wheelock, J. M. 1969. Phytoplankton ecology in Wabamun Lake and the effect of thermal pollution. M.Sc. Thesis, Dept. of Botany, Univ. Alberta, Edmonton.

Whitehouse, J. W. 1971. Some aspects of the biology of Lake Trawsfyndd; a power station colling pond. Hydrobiologia 38: 253-288.

Wiederholm, T. 1971. Bottom fauna and cooling water discharges in a basin of Lake Malaren. Inst. of Freshwater Res., Drottningholm Rep. No. 51: 197-214.

Wiggins, G. B. 1977. Larvae of the North American Caddisfly Genera (Trichoptera). Toronto Univ. Press.

Wunder, W. 1949. Fortschrittliche Karpfenteichwirtschaft. Ergebnisse 20 jähriger Untersuchungen auf dem Bebiete der Teichforschung. Stuttgart.

APPENDIX 1

Systematic breakdown of the macroinvertebrate species found in Lake Wabamun.

Phylum Annelida
  Class Oligochaeta
    Family Tubificidae
      Genus *Limnodrilus* Claparède
        Limnodrilus hoffmeisteri Claparède
      Genus *Tubifex* Lamarck
        Tubifex tubifex (Müller)
        Tubifex kessleri americanus Brinkhurst and Cook

    Family Naididae
      Genus *Stylaria* Lamarck
        Stylaria lacustris Linnaeus

      Genus *Nais* Müller
        Nais pardalis Piquet
        Nais sp. #1 *(cf. elinguis)*

Notes: This species is probably *Nais elinguis* Müller.

      Genus *Chaetogaster* Von Baer
        Chaetogaster diaphanus (Gruithuisen)
        Chaetogaster sp. #1

Notes: This species is probably *Chaetogaster crystallinus* Vejdovsky.

      Genus *Pristina* Ehrenberg
        Pristina sp. #1

Notes: This species keys to *P. osborni* using Brinkhurst and Jamieson's (1971) key to Naididae, but sexually mature specimens were never found. It is possible that the specimens obtained may actually be very immature *Tubifex*.

General references for oligochaete identification were Brinkhurst and Jamieson (1971) and Goodnight (1959). Brinkhurst's (1965) review of the Tubificidae and his (1964) review of the Naididae were also consulted.

Class Hirudinea
  Family Glossophonidae
    Genus *Glossophonia* Johnson
      Glossophonia complanata (Linnaeus)
    Genus *Marvinmeyeria*
      Marvinmeyeria lucida (Moore)
    Genus *Helobdella* E. Blanchard
      Helobdella stagnalis (Linnaeus)

  Family Erpobdellidae
    Genus *Erpobdella* Blainville
      Erpobdella punctata (Leidy)
    Genus *Nephelopsis* Verrill
      Nephelopsis obscura Verrill

Notes: Davies (1971) presented a key to the known Canadian leeches and Moore (1964, 1966) gave keys to the Alberta species, and presented local distribution records. Some studies have been performed on the feeding habits of some Alberta leeches. Davies and Everett (1975) presented feeding data on all of the species mentioned here except *M. lucida*. Davies and Reynoldson (1975) described the life history of *H. stagnalis* from an Alberta pond. The literature on the responses of leeches to pollutants of various types has been reviewed by Sawyer (1974). Some of this material pertains to the effects of thermal discharges.

Phylum Platyhelminthes
  Class Turbellaria
    Family Planariidae
      Genus *Dugesia* Girard
        Dugesia tigrina (Girard)

  Class Rhabdocoela
    Family Typhloplanidae
      Genus *Mesostoma* Ehrenberg
        Mesostoma sp. #1

Notes: The keys to Turbellaria which were consulted were from Pennak (1953), Hyman (1959), and Jones (1959). A study has been carried out on the life history of *D. tigrina* of Lake Wabamun by Folsom (1976).

Phylum Mollusca
  Class Pelecypoda
    Family Unionidae
      Genus *Anodonta* Lamarck
        Anodonta grandis grandis Say

    Family Sphaeriidae
      Genus *Sphaerium* Scopoli
        Subgenus *Musculium* Link
          Sphaerium (Musculium) lacustre (Müller)
      Genus *Pisidium* Pfeiffer
        Subgenus *Cyclocalyx* Dall
          Pisidium (Cyclocalyx) casertanum (Poli)
          Pisidium (Cyclocalyx) compressum Prime

Notes: Molluscan specimens were identified using the keys of Clarke (1973). This review of Canadian molluscs also summarizes the available data on the distribution and habitat preferences of each of the known species.

A helpful reference dealing with the biology of *Pisidium* is that of Heard (1965). Considerable data on the seasonal dynamics, reproductive biology and habitats of both *P. casertanum* and *P. compressum* is available in this paper.

  Class Gastropoda
    Subclass Prosobranchia
      Family Valvatidae
        Genus *Valvata* Müller
          Valvata tricarinata (Say)
          Valvata sincera Say

    Subclass Pulmonata
      Family Lymnaeidae
        Genus *Lymnaea* Lamarck
          Lymnaea stagnalis Linné
          Lymnaea elodes (Say)

      Family Physidae
        Genus *Physa* Draparnaud
          Physa gyrina Say

Notes: Studies concerning the ecology of the genus *Physa* are present in the literature. A paper by DeWitt (1965) dealt with the life history of *P. gyrina*. Sankurathri and Holmes (1976a) studied the effects of thermal effluents on the seasonal dynamics of *P. gyrina* in Lake Wabamun and McMahon (1975) dealt with the effects of thermal discharges on populations of *P. virgata*.

Family Planorbidae
  Genus *Gyraulus* Charpentier
    Gyraulus deflectus (Say)
    Gyraulus parvus (Say)

  Genus *Armiger* Hartmann
    Armiger crista (Linnaeus)

  Genus *Promenetus* Baker
    Promenetus exacuous (Say)

  Genus *Helisoma* Swainson
    Subgenus *Helisoma*
      Helisoma (Helisoma) anceps (Menke)
    Subgenus *Pierosoma* Dall
      Helisoma (Pierosoma) trivolvis (Say)
      Helisoma (Pierosoma) binneyi (Tyron)

Notes: Baker (1945) published a detailed account of the morphology and systematics of the family Planorbidae.

Phylum Arthropoda
  Class Crustacea
    Order Ostracoda

Notes: Ostracods were identified from the keys published by Delorme (1967), and Tressler (1959) as well as from the species descriptions given by Delorme (1970a, 1970b, 1970c, 1970d, and 1971).

Family Cypridae
  Subfamily Cypridinae
    Genus *Cyprinotus* Brady
      Cyprinotus glauca Furtos
    Genus *Cypriconcha* Sars
      Cypriconcha barbata (Forbes)

  Subfamily Cypridopsinae
    Genus *Potamocypris* Brady
      Potamocypris smaragdina (Vavra)

Notes: Ferguson (1944) gave data on the life history of *P. smaragdina*.

Family Cyclocyprididae
  Genus *Cyclocpris* Brady and Norman
    Cyclocypris ampla Furtos
    Cyclocypris serena (Koch)
    Cyclocypris sp. #1

Notes: This species keys to *C. ovum* (Jurine) on Tressler's (1959) key and the specimens agree in most respects with the accompanying description. Delorme (1970c), however, did not report this species from Canadian waters.

Genus *Cypria* Zenker
  Cypria opthalmica (Jurine)

Family Candonidae
  Genus *Candona* Baird
    Candona candida (Mueller)
    Candona decora Furtos
    Candona distincta Furtos
    Candona rawsoni Tressler
    Candona ohioensis Furtos
    Candona sp. #1

Notes: This species resembles *C. punctata* with regard to size and the punctation of the valves. The valves of *Candona* sp. #1 differ considerably in shape from those described for *C. punctata* by Delorme (1971).

Family Limnocytheridae
  Genus *Limnocythere* Brady
    Limnocythere itasca Cole

Family Darwinulidae
  Genus *Darwinula* Brady and Norman
    Darwinula stevensoni Brady and Robertson

Notes: McGregor (1969) studied the population dynamics of *D. stevensoni*.

Some literature has been published on the temperature preferences and phenologies of various ostracod species. Data of this nature was given for the majority of the ostracod species occurring in Lake Wabamun in an unpublished study of Saskatchewan ostracodes by Delorme (1964, unpublished).

The only study on ostracods actually performed within Alberta, to my knowledge, is that of Johnston (1966) on the ostracods found in highway borrow pit ponds.

Order Amphipoda
  Family Taltridae
    Genus *Hyalella* Smith
      Hyalella azteca (Saussure)

  Family Gammaridae
    Genus *Gammarus* Fabricius
      Gammarus lacustris Sars

Notes: Amphipods were identified using the keys given by Bousfield (1958). This reference also gives descriptions of all Canadian freshwater amphipods. Most of the older literature on *Hyalella azteca* was reviewed by Cooper (1965), who did a thorough life history study of this species at Sugar Loaf Lake.

Gammarus lacustris is a holarctic species and data on its life history and ecology are present from both old and new world locations. Hynes (1955) reviewed the European literature and presented considerable data on *G. lacustris* populations in the British Isles. Menon (1966) reported on the life history of *G. lacustris* from Big Island Lake, Alberta.

Class Arachnida
  Order Hydracarina

Notes: The Hydracarina taken at Lake Wabamun were not identified.

Class Insecta
  Order Odonata
    Suborder Anisoptera
      Family Libellulidae
        Subfamily Corduliinae
          Genus *Tetragoneuria* Hagen
            Tetragoneuria spinigera (Selys)

        Subfamily Libellulinae
          Genus *Sympetrum* Newman
            Sympetrum costiferum (Hagen)
            Sympetrum danae Sulzer

      Family Aeschnidae
        Genus *Aeschna* Fabricius
          Aeschna eremita Scudder

Suborder Zygoptera
  Family Lestidae
    Genus *Lestes* Leach
      Lestes sp. #1

  Family Coenagrionidae
    Genus *Ischnura* Charpentier
      Ischnura sp. #1

    Genus *Enallagma* Charpentier
      Enallagma sp. #1
      Enallagma sp. #2

Notes: A number of reference works were used in the identification of the Odonata. Nymphs alone are treated at the generic level by Gloyd and Wright (1959). Nymphs and adults of the Libellulidae were treated by Walker and Corbet (1975, Vol. 3). Aeschnids were identified using the keys and descriptions of Walker (1958, Vol. 2), and Walker (1953, Vol. 1) was used in the identification of Zygoptera.

The association of larvae with adults was accomplished in only 2 cases by rearing. *Tetragoneuria* and *Aeschna* were reared in laboratory aquaria from larvae of the ultimate instar. Larvae of *Sympetrum* spp. were not taken at any of the sampling stations and consequently, they are probably confined to areas immediately adjacent to the lakeshore where I observed *Sympetrum* larvae frequently. No attempt was made to determine the differences between the larvae of the 2 species which were caught as adults.

The identity of *Lestes* sp. #1 and *Ischnura* sp. #1 was not determinable since they were obtained only as larvae. *Enallagma* adults of 2 distinct species were caught, but they did not key properly on Walker's (1953) key to Zygopteran species. The larvae were never reared, but it appeared from pigmentation patterns that 2 distinct species were present.

Order Ephemeroptera
  Family Caenidae
    Genus *Caenis* Stephens
      Caenis simulans McDunnough

  Family Leptophlebiidae
    Genus *Leptophlebia* Westwood
      Leptophlebia pacifica (McDunnough)

    Genus *Paraleptophlebia* Lestage
      Paraleptophebia sp. #1

  Family Baetidae
    Genus *Baetis* Leach
      Baetis sp. #1 (*cf. B. parvis* Dodds)
      Baetis sp. #2 (*cf. B. moffati* Dodds)

    Genus *Callibaetis* Eaton
      Callibaetis coloradensis Banks

  Family Ephemeridae
    Genus *Ephemera* Linnaeus
      Ephemera sp. #1

Notes: Adult and larval material of the Order Ephemeroptera were keyed using Needham, Travers and Hsu (1935), but recent synonymizations resulting from the systematic work of Edmunds *et al.* (1976) places identifications made from the former reference in doubt. The *Callibaetis* adult males keyed to *C. hageni* in Needham *et al.* (1935), but the females did not fit the description given for that species. Berner (pers. com.) places this material in *C. coloradensis*. The *Leptophlebia* adults all keyed to *Blasturus vibex* in Needham *et al.* (1935), but Edmunds *et al.* (1976) has synonymized *B. vibex* under *Leptophlebia pacifica*. The *Baetis* adults were identified from Needham *et al.* (1935) and this is true also of the *C. simulans* adults.

Association between larvae and adults was done by rearing for *C. simulans*, *L. pacifica*, and *C. coloradensis*. Some *Baetis* larvae were caught, but their identity is unknown. *Paraleptophlebia* sp. #1 and *Ephemera* sp. #1 were caught only as larvae.

Order Trichoptera
Family Polycentropodidae
Genus *Polycentropus* Curtis
Polycentropus sp. #1

Notes: This species was caught only as a larva and the specimens key to *P. interruptus* (Banks) in Ross (1944). The larvae appear identical in all respects to those described by Ross (1944).

Polycentropus sp. #2

Notes: This species was also caught as larvae. In Ross's (1944) key, the specimens key down to the couplet containing *P. cinereus* and *P. centralis* Banks. The Lake Wabamun species is clearly distinct from either of these species, however. It is also different from that illustrated as *Polycentropus* sp. by Wiggins (1977, Fig. 15.5).

Genus *Neureclipsis* McLachlan
Neureclipsis bimaculata (Linnaeus)

Notes: Adult specimens which keyed to *N. bimaculatus* in Ross (1944) were caught in considerable numbers and larvae which fit the description of this species given by Ross, and which are identical to the illustration given by Wiggins (1977, Fig. 15.2), were also obtained. The occurrence of *N. bimaculata* in Lake Wabamun is of considerable interest since Wiggins (1977) reports it to be found only under lotic conditions. The larvae were found only at Stations 1 and 7 where the flow of the heated water was always detectable, but the adults ranged considerable distances from any flowing water.

Family Hydroptilidae
Genus *Hydroptila* Dalman
Hydroptila albicornis Hagen

Notes: This identification was made from adult male specimens which were obtained along the shoreline of the lake. They were keyed to this species in Ross (1944). Larvae which keyed to *Hydroptila* were also caught and it is assumed that they belong to *H. albicornis*.

Genus *Oxyethira* Eaton
Oxyethira sp. #1

Notes: Many adults which keyed to *Oxyethira* on Ross' (1944) key were obtained. These specimens all appeared to be of one species, but they would not key to the species level on Ross's key. Larvae of *Oxyethira* were extremely abundant on macrophytes in Lake Wabamun, and they too appeared to be of one species. Many pharate adults which had died in this condition were caught and the cases contained the fragmented larval exuviae, thus enabling the association of the larvae and the adults.

Family Phryganeidae
Genus *Phryganea* Linnaeus
Phryganea cinerea Walker

Genus *Agrypnia* Curtis
Agrypnia straminea Hagen
Agrypnia vestita (Walker)

Notes: These 3 phryganeid species were reared in the laboratory from larvae of the ultimate instar. The adults were keyed to species in Ross (1944), and the larvae key to species on the key published by Wiggins (1960), and fit the descriptions given in this paper.

Genus *Fabria* Milne
Fabria inornata (Banks)

Notes: Adults of this species were never obtained, and the larvae closely resemble those of *A. vestita* in their morphology and coloration. These larvae, however, build the very distinctive case illustrated for this species by Wiggins (1977, Fig. 14.3).

Family Limnephilidae
Genus *Limnephilus* Leach
Limnephilus infernalis (Banks)

Notes: *L. infernalis* was reared in the laboratory from larvae of the ultimate instar. The adults were keyed to this species on the key to Alberta limnephilids of Nimmo (1971), and they fit perfectly the descriptions of this species contained in this paper and in an earlier paper by Nimmo (1965). The larvae fit the discription available in Nimmo (1965).

Genus *Anabolia* Stephens
  Anabolia bimaculata (Walker)

Notes: This species was not found at any of the sampling stations, but it was common in marshy areas around the periphery of certain portions of the lake. A few adults which were caught were identified from the key of Nimmo (1971). The larva resembles perfectly the illustration of *A. bimaculata* given by Wiggins (1977, Fig. 10.3).

Family Molannidae
  Genus *Molanna* Curtis
    Molanna flavicornis Banks

Notes: This species was reared from larvae in an aquarium. The adult keys to *M. flavicornis* in Ross (1944) and the larvae resemble perfectly Wiggins' (1977, Fig. 11.1) illustration of this species.

Family Leptoceridae
  Genus *Ceraclea* Stephens
    Ceraclea sp. #1

Notes: The adults of this species were never obtained. The larvae key to *Athripsodes (=Ceraclea) alagmus* Ross, but this key (Ross, 1944) does not contain all of the larvae for the known nearctic species.

Genus *Triaenodes* McLachlan
  Trianodes tarda Milne

Notes: Adults which keyed to *T. tarda* were collected frequently, but the larvae of this genus which were collected all keyed to *T. aba* on the key of Ross (1944). The larvae and the adult are however definitely conspecific since a puparium containing a dead pharate adult male together with half of the larval head capsule was found at Station 1. The *Triaenodes* larvae from Lake Wabamun are very similar to that illustrated by Wiggins (1977, Fig. 9.7) in both pigmentation and structure.

Genus *Oecetis* McLachlan
Oecetis cinerascens (Hagen)
Oecetis ochracea (Curtis)
Oecetis inconspicua (Walker)
Oecetis immobilis (Hagen)
Oecetis sp. #1

Notes: Five species of *Oecetis* were caught as adults. The first 4 named keyed out in Ross (1944), and the last named did not. Although no *Oecetis* larvae have been reared in the laboratory, specimens which key to the first 4 named species on Ross's (1944) key to larval *Oecetis* have been obtained. The larva which I have associated with *Oecetis* sp. is tentatively associated since it is possible that more species of this genus are present.

Genus *Mystacides* Berthold
Mystacides interjecta (Banks)

Notes: All North American records of this species prior to that of Wiggins (1977) deal with it under the name *M. longicornis* (Linnaeus). This species was reared in the laboratory. The adult keys to *M. longicornis* in Yamamoto and Wiggins (1964) as does the larva and the pupa.

Family Lepidostomatidae
Genus *Lepidostoma* Rambur
Lepidostoma sp. #1

Notes: No *Lepidostoma* larvae were reared, but both adults and larvae of this genus have been collected. The specimens were keyed on the key of Ross (1944).

Family Helicopsychidae
Genus *Helicopsyche* Hagen
Helicopsyche borealis Hagen

Notes: *Helicopsyche* larvae were not reared. There is little doubt, however, about the identity of the larva. It resembles perfectly that illustrated for *H. borealis* by Wiggins (1977, Fig. 5.1), and it fits the descriptions given by Vorhies (1909) and Elkins (1936). Many adults of this species were caught and they were keyed to *H. borealis* in Ross (1944).

Order Coleoptera
Family Haliplidae
Genus *Haliplus* Latreille
Haliplus sp.

Notes: The *Haliplus* larvae were identified to the generic level on the larval key of Leech and Sanderson (1959). This was the only coleopteran species found at the sampling stations and although it was never numerous it was found at most of the stations of 1.5 m depth. A considerable number of coleopterans are present around the marshy shoreline regions of the lake. These include several dytiscids, at least one species of gyrinid, and probably several others. No attempt was made to study the shoreline fauna and with the exception of some groups where the majority of the species occurred within the lake proper, the shoreline species were not identified.

Order Hemiptera

Notes: Several species of corixids and at least one species of notonectid were present around the shoreline regions of the lake. They did not occur at any of the sampling stations within the lake proper.

Order Diptera
  Family Culicidae
    Subfamily Chaoborinae
      Genus *Chaoborus* Lichtenstein
        Chaoborus sp. #1
        Chaoborus sp. #2

Notes: The *Chaoborus* specimens were not identified to the species level.

Family Ceratopogonidae
  Genus *Palpomyia* Megerle
    Palpomyia sp. #1

Notes: Some larval ceratopogonids were found at most of the littoral stations. They all appeared very similar and keyed to *Palpomyia* on Thomsen's (1937) larval key. Possibly several species are present.

Family Chironomidae
  Subfamily Tanypodinae
    Tribe Tanypodini
      Genus *Tanypus* Meigen
        Tanypus stellatus Coquillet

Notes: All adult male Tanypodinae were keyed to species using Roback's (1971) key.

T. stellatus was reared. The larvae are similar to those described for this species by Roback (1968).

Tribe Macropelopiini
  Genus *Derotanypus* Roback
    Subgenus *Merotanypus* Roback
      Derotanypus (Merotanypus) alaskensis (Malloch)

Notes: This species was not taken during this study, but specimens were recorded from Lake Wabamun by Strickland (May 8, 1932, cited in Roback, 1971, p.95). It is likely that this species is present in small numbers within the lake. *D. alaskensis* is a very commonly recorded northwestern species and Roback (1971) gives records of its occurrence in the Edmonton area and in many other localities of northwestern Canada.

Genus *Procladius* Skuse
Subgenus *Psilotanypus* Kieffer
Procladius (Psilotanypus) bellus (Loew)

Notes: *Procladius bellus* (*sensu* Roback, 1971) is a very widely distributed and morphologically variable species. Roback (1971, p. 163-164) recognizes 3 color varieties of the species, the *pusillus* form, the *riparius* form, and the *malifero* form. The *pusillus* form is the smallest and most lightly colored, and the *malifero* form is the largest and most darkly colored. During this study, imagines of the *pusillus* form and of the *malifero* form were obtained from laboratory-reared fourth instar larvae, and the larvae which gave rise to the *malifero* imagines were much larger and quite different structurally from those that gave rise to the *pusillus* imagines. No published comparison of the larvae of these forms is available in the literature. The fact that these forms are distinguishable even as larvae may indicate that 2 distinct species of *P. (Psilotanypus)* are involved here.

The larva described under the name *P. bellus* by Hamilton (1965) is identical to that which yielded the *pusillus* type imagines from Lake Wabamun.

Subgenus *Procladius* Skuse
Procladius (Procladius) denticulatus Sublette

Notes: Two males of this species were reared from larvae. They key to *P. denticulatus* on Roback's (1971, p. 150) key, but the structure of strut 2 is atypical in that the large denticles are not confined to the apical region of the strut. Larvae of *P. denticulatus* were described by Hamilton (1965) and the Lake Wabamun specimens match this description well.

Procladius (Procladius) freemani Sublette

Notes: Two males of this species were reared from larvae. Larvae of *P. freemani* were described by Hamilton (1965) and in most respects the larvae from Lake Wabamun resemble those from Marion Lake. The Lake Wabamun larvae have, however, a considerably larger basal antennal segment (190-205 μ *versus* 175-190 μ).

Procladius (Procladius) ruris Roback

Notes: This species was never reared. It is the largest of the *Procladius* species caught as adults at Lake Wabamun and it is tentatively associated with the largest type of larva. The fact that the pupation and disappearance of the larva is well timed with the appearance of the adult *P. ruris* suggests that the association is likely correct. Both the adults and the larvae resemble the species named as *Procladius* sp. A by Hamilton (1965).

Procladius (Procladius) sp. #1

Notes: This species was obtained only as larvae. It is distinct from the larvae of the other 3 species of the subgenus in that the lingua of the hypopharynx is extremely wide with its outer margin considerably more flared than normally seen in *Procladius*. It may be the larva of *Procladius (Procladius) abetus* Roback, which was originally described from specimens collected at Lake Wabamun by Strickland (Roback, 1971, p. 185-186).

Tribe Coelotanypodini
Genus *Clinotanypus* Kieffer
Clinotanypus sp. #1

Notes: This species was taken only as larvae and it was never reared. It will not key on Roback's (1957, p. 46) key to larval *Clinotanypus*, but it is very similar to that described as *Clinotanypus* sp. A by

Hamilton (1965). Minor differences are present for certain characters and consequently, the Marion Lake specimens may not be conspecific with those I have found in Lake Wabamun.

Tribe Pentaneurini
Genus ? (*Thienemannimyia* group of Roback, 1971)
Pentaneurini sp. #2

Notes: This species was taken only as larvae. The larvae were keyed to the *Thiennemannimyia* group of genera on an unpublished key by Hamilton and they also resembled the description and illustration given for this group of genera by Stewart and Loch (1973). In Roback's (1957, p. 30) key to larval Pentaneurini, the larvae run to couplet 17 which contains many of the species which presently are in the *Thienemannimyia* group of genera.

Genus *Labrundinia* Fittkau
Labrundinia pilosella (Loew)

Notes: Adults which keyed to this species were caught in considerable numbers. Adults were never obtained from reared larvae, but larvae resembling those described for *Pentaneura pilosella* in Roback (1957) and in Johannsen (1938) were frequently caught. These larvae appear to belong to one species only and they are tentatively associated with the adult *L. pilosella*.

Genus *Ablabesmyia* Johannsen
Subgenus *Karelia* Roback
Ablabesmyia (Karelia) peleensis (Walley)

Notes: This species was reared to the adult from the larva. The larvae agree with the description available for the species (Johannsen, 1938) and key to *Pentaneura peleensis* in Roback's (1957) key to *Pentaneura*.

Subgenus *Ablabesmyia* Johannsen
Ablabesmyia (Ablabesmyia) basalis (Walley)

Notes: The larva from which a male *A. basalis* was reared resembles the larva of *A. monilis* as described by Roback (1957), Johannsen (1938), and Hamilton (1965), and in all likelihood the larva of *A. basalis* will prove difficult to distinguish from that of *A. monilis*.

Ablabesmyia (Ablabesmyia) sp. #1

Notes: Only larvae of this species were found. It is slightly smaller than the larva of *A. basalis* and on this basis it probably belongs in the subgenus *Ablabesmyia*. It is distinguishable from the other two *Ablabesmyia* species by the fact that it possesses 3 basal segments on the maxillary palps, rather than two.

Subfamily Diamesinae
Genus *Potthastia* Kieffer
Potthastia cf. longimanus Kieffer

Notes: No adult Diamesinae were obtained, and the identification of the *Potthastia* larvae was based on the very distinctive labial structure described for this species by Pagast (1933). Roback (1953) illustrated a similar labial plate for a specimen which he believed was *P. longimanus*. The specimens key to the genus *Potthastia* on the key of Pankratova (1970).

Subfamily Orthocladiinae
Genus *Acricotopus* Kieffer
Acricotopus sp. #1

Notes: This species keys to *Acricotopus* using Hirvenoja's (1973) key to the genera of orthoclad larvae. The structure of the anterior central setae is not trifid, and hence, this species does not key properly to *Acricotopus* on Pankratova's (1970) key to orthoclad larvae. In all of its structures the larva greatly resembles Hirvenoja's illustration of *A. lucens* Zett. No adults were obtained for this species.

Genus *Corynoneura* Winn.
Corynoneura sp. #1

Notes: Both larvae and adults which keyed to *Corynoneura* were obtained, but none were ever reared. Both the larval collection and the adults seem to exhibit only one species, and so probably they are correctly associated. The adults key to *Corynoneura* on Brundin's (1956) key and the larvae were identified using Pankratova's (1970) key to orthoclad larvae.

Genus *Cricotopus* van der Wulp
Subgenus *Cricotopus*
Cricotopus (Cricotopus) bicinctus (Meigen)

Notes: This species was recorded quite frequently at Lake Wabamun, but only as an adult. The larva of this species is quite well known and descriptions by Oliver (1977) and by Hirvenoja (1973) would both allow the larvae to be easily identified if it were found. Possibly this species is confined to the shoreline areas of the lake.

Cricotopus (Cricotopus) sp. #1 *(bicinctus* group*)*

Notes: This species was collected only as a larva and it was never successfully reared. It would key to *C. verriensis* Goetgh. if the hair pencils on the abdonimal segments were shorter. The mandible possesses no spines along the inner margin, so consequently, the larva is probably not that of *C. bicinctus*.

Cricotopus (Cricotopus) sp. #2 *(cylindraceus* group*)*

Notes: This species was collected only as larvae and it was never reared. These larvae key to *C. patens* Hirvenoja by virtue of the fact that the second lateral tooth on the labial plate is significantly reduced. In most details it does not fit exactly the description of the *C. patens* larva given by Hirvenoja (1973, p. 221). This larva is very abundant in Lake Wabamun in sandy littoral areas.

Subgenus *Isocladius* Kieffer

Cricotopus (Isocladius) sp. #1 *(sylvestris* group*)*

Notes: This species was collected only as larvae around the marshy shoreline around the east end of the lake. It was never reared. Using Hirvenoja's (1973, p. 259) key, this larva keys to *C. sylvestris* (Fabricius) and it fits most details of the description given for this species (Hirvenoja, 1973, pp. 282-283).

Cricotopus (Isocladius) sp. #2 *(sylvestris* group*)*
Cricotopus (Isocladius) sp. #3 *(sylvestris* group*)*
Cricotopus (Isocladius) sp. #4 *(sylvestris* group*)*
Cricotopus (Isocladius) sp. #5 *(sylvestris* group*)*

Notes: These constitute 4 distinct types of larvae all of which key to *C. ornatus* (Meigen) on Hirvenoja's key to the *C. sylvestris* group. One specimen of *Cricotopus (Isocladius)* sp. #2 has been reared to an adult female which resembles *C. tricinctus* (Meigen). The pupa of this species also resembles that of *C. tricinctus*.

Cricotopus (Isocladius) pilitarsis (Zett.)

Notes: This species was collected as adults only. It was never reared from a larva. It was identified from Hirvenoja's key to adult males of the *sylvestris* species group (Hirvenoja, 1973, p. 258). This species is probably the adult of one of the preceeding types of *sylvestris* group larvae. No description of the larvae of *C. pilitarsis* has as yet been published.

Cricotopus (Isocladius) sp. #6 *(intersectus* group*)*

Notes: This species was not reared to an adult. The larvae key to *C. intersectus* (Staeg.) in Hirvenoja (1973, p. 255).

Cricotopus (Isocladius) sp. #7 (*laricomalis* group)

Notes: This species was not reared to an adult. The larvae key to *C. laricomalis* (Edw.) in Hirvenoja's (1973) key to species groups of *Isocladius*.

Cricotopus (Isocladius) tricinctus (Meigen)

Notes: Some adult males which keyed to *C. tricinctus* (Hirvenoja, 1973, p. 258) were caught. These may be the males of *Cricotopus (Isocladius)* sp. #2 since no larvae which keyed to *C. tricinctus* were found.

For the time being, the status of the genus *Cricotopus* in Lake Wabamun is unclear. There appear to be at least 3 species of *C. (Cricotopus)* present and at least 7 species of *C. (Isocladius)*. If *C. pilitarsis* and *C. tricinctus* prove not to be the adults of any of the numbered larval forms, this would mean that at least 12 species of this genus were present.

Genus *Heterotrissocladius* Sparck
Heterotrissocladius sp. #1

Notes: These larvae key to the genus *Heterotrissocladius* on Saether's (1976) key and on that of Pankratova (1970) as well. Adult males which key to this genus were also caught. Both the adults and the larvae reach *H. changi* Saether with Saether's (1975) key to *Heterotrissocladius*.

Genus *Orthocladius* van der Wulp
Subgenus *Orthocladius*
Orthocladius (Orthocladius) obumbratus (Johannsen)

Notes: Both adults and larvae which keyed to this species in Saponis' (1977) treatment of *O. (Orthocladius)* were found. The adult males keyed to this subgenus in Brundin (1956) and the larvae keyed to the genus *Orthocladius* on Pankratova's (1970) larval key.

Genus *Nanocladius* Kieffer
Subgenus *Nanocladius*
Nanocladius (Nanocladius) rectinervis (Kieffer)

Notes: One male of this species was reared. The male keyed to *Microcricotopus* Thien., and Harn. (=*Nanocladius* Kieff.) on Brundin's (1956) generic key to adult orthocladiinae. The larva keyed to the same genus on Pankratova's (1970) key. Both fit the description given for *N. rectinervis* by Saether (1977) and they key to this species on his keys (Saether, 1977, pp. 6-11).

Genus *Parakiefferella* Thien.
Parakiefferella cf. torulata Saether

Notes: This species was not reared, but both adults and larvae which resemble Saether's (1969) description of *P. torulata* were found. Brundin (1956) was used to key the adult to the generic level and Pankratova (1970) was used to key the larvae. Further study is necessary on these specimens before it can be said with certainty whether or not they are *P. torulata* Saether.

Genus *Psectrocladius* Kieffer

Notes: Six easily distinguishable types of *Psectrocladius* larvae were encountered. None were reared, and no adults were caught. The larvae all keyed to *Psectrocladius* on Pankratova's key. Characters most useful in distinguishing the types of larvae were the shapes of the labial plates, the size and shape of the anterior central setae of the labrum (SI), and the length of the basal antennal segment.

Psectrocladius sp. #1

Notes: This species resembles *P. psilopterus* Kieffer as illustrated by Pankratova (1970, p. 220).

Psectrocladius sp. #2
Psectrocladius sp. #3
Psectrocladius sp. #4

Notes: The labial plates and the SI of these 3 species resemble that illustrated for *P. simulans* Johannsen by Pankratova (1970, Fig. 135) in their basic structure.

Psectrocladius sp. #5

Notes: The labial plate of this species is of the *P. simulans* type but the SI is very different.

Psectrocladius sp. #6

Notes: This species is strikingly similar to *P. dilatatus* van der Wulp based on the illustration given for *P. dilatatus* by Pankratova (1970, Fig. 136).

Genus *Thienemanniella* Kieffer
Thienemanniella sp. #1
Thienemanniella sp. #2

Notes: Adults of these species were never obtained. They were keyed to the generic level on Pankratova's (1970) key.

Genus *Zalutschia* Lipina
Zalutschia lingulata pauca Saether

Notes: Both larval and adult specimens which keyed to this species in Saether (1977, pp. 186-193) were found. The species and the subspecies were both described in this reference.

Subfamily Chironominae
Tribe Chironomini

Notes: Except when otherwise stated, all species determinations of adult Chironomini were based on the keys and descriptions of Townes (1945).

Genus *Chironomus* Meigen
Subgenus *Chironomus*
Chironomus (Chironomus) plumosus (Linnaeus)-*plumosus* type

Notes: This species was reared. The larva was a *plumosus* type (After Lenz, 1921) and is readily distinguishable from that of other *Chironomus* species. Johannsen (1938) gave a description for the larva of this species which fits the Lake Wabamun specimens reasonably well.

Chironomus (Chironomus) plumosus-semireductus type Lenz

Notes: This form is a larval variant of *C. plumosus* described by Lenz (1921). Saether (1975) and other authors have considered this larval morph separately from that of *C. plumosus-plumosus* due to the fact that it has usually been associated with less eutrophic situations than has been the case for *C. plumosus-plumosus*. The *C. plumosus-semireductus* larvae on the basis of antennal characters as well as the characters pertaining to the ventral tubules described by Lenz (1921).

Chironomus (Chironomus) maturus Johannsen

Notes: This species keys to *C. decorus* Johannsen in Townes (1945), who considered *C. maturus* as a synonym of *C. decorus*. All stages fit the descriptions given by Sublette and Sublette (1974) for *C. maturus*.

Chironomus (Chironomus) sp. #2

Notes: This species is probably new. It keys to *C. tuxis* (Curran) in Townes (1945), but differs considerably from *C. tuxis* with regard to hypopygial characters of the male imago. The male hypopygium of *Chironomus* sp. #2 most closely resembles that of *C. staegeri* (Lundbeck). All stages of *C. staegeri* are, however, much larger than *Chironomus* sp. #2, and larvae of *C. staegeri* (Canadian National Collection, Biosystematics Research Institute, Ottawa) differ from *Chironomus* sp. #2 in possessing crenulated paralabial plates.

Chironomus (Chironomus) anthracinus Zetterstedt

Notes: This species was reared from a larva identical to that described by Rempel (1936). Rempel identified his specimens as *C. hyperboreus*, but Townes (1945, p. 130) considered Rempel's material to be *C. anthracinus*. Hamilton (1965) described identical material under the name *C. rempelii* Thienemann, a name applied to Rempel's specimens by Thienemann (1954). Thienemann considered the North American material as distinct from the European *C. anthracinus* due to the fact that this species always had a *thummi* or *riparius* type of larva in European lakes, whereas Rempel's specimens had larvae of the *plumosus* type. The status of *C. anthracinus* in North America has been discussed by Saether (1975).

Chironomus (Chironomus) riparius Meigen

Notes: This species was not reared, and only imagines of *C. riparius* were collected. No larvae fitting the description of *C. riparius* (= *C. viridicollis* in Malloch, 1915 = *C. militaris* in Johannsen, 1938) were found at any of the sampling stations. The larvae are possibly present in marshy areas near the shoreline.

Chironomus (Chironomus) hyperboreus Staeger

Notes: The adult male of this species will key to *C. hyperboreus* in Townes (1945, p. 117-118), but the leg ratio of the Wabamun specimens varies more than was indicated by Townes. *Chironomus hyperboreus* males were reared in an aquarium from larvae of the *salinarius* type. A brief description of the larva of *C. hyperboreus* was given by Søgaard-Andersen (1937) and the larvae from Lake Wabamun agree with the details given in that paper.

Chironomus (Chironomus) sp. #1

Notes: The larva of this species is of the *plumosus* type and resembles that of *C. anthracinus* in size and general appearance, but differs from it with regard to the positioning of the ring organ of the basal antennal segment.

Subgenus *Camptochironomus* Kieffer
Chironomus (Camptochironomus) tentans Fabricius

Notes: This species was reared from a *plumosus* type of larvae which exhibited projections from segment 10 which were more than 25% of the length of the ventral tubules.

Subgenus *Chaetolabis* Townes
Chironomus(Chaetolabis) atroviridis (Townes)

Notes: This species was reared from a larva of the *thummi* type. A description of the larva of *C. atroviridis* is presently not available in the literature.

Genus *Cryptochironomus* Kieffer
Cryptochironomus psittacinus (Meigen)

Notes: This species was reared. Saether (1977, p. 87) refers to an inconsistency between the European *C. psittacinus* (*sensu* Reiss, 1968, p. 196) and the North American material under this name (*sensu* Townes, 1945, p. 100, Fig. 114). He considers that the correct name for the North American material so far known as *C. psittacinus* is the first available synonym *Cryptochironomus stylifera* (Johannsen).

Genus *Demicryptochironomus* Lenz
Demicryptochironomus sp. #1

Notes: This species was not reared and it is unlikely that I have caught its adults. According to Saether (1977, p. 133) this genus contains only two nearctic species, *D. cuneatus* (Townes) and *D. fastigatus* (Townes), both of which were considered as species under *Harnischia (Harnischia)* Kieffer. None of the adult males from my collections, which keyed to the subgenus *Harnischia* in Townes (1945, p. 147), were keyed to either of these two species. The larvae of *Demicryptochironomus* from Lake Wabamun were identical to those illustrated as *D. cuneatus* by Saether (1977, p. 132, Fig. 48).

Genus *Dicrotendipes* Kieffer
Dicrotendipes nervosus (Staeger)

Notes: This species was reared. The immature stages are identical to reared exuviae from the Canadian National Collection whose adults were determined to be *D. nervosus*. These larvae are very different from those described by Hauber and Morrisey (1945) under the name *Tendipes (Limnochironomus) lucifer*. Townes (1945, p. 108) synonymized *T. lucifer* under *T. nervosus (= D. nervosus)*, but the differences between these larvae could indicate that several species are grouped under *D. nervosus*. The larva of *D. nervosus* is readily distinguishable from all other types of *Dicrotendipes* larvae which occur in Lake Wabamun.

Dicrotendipes modestus (Say)

Notes: This species was reared in the laboratory. The immatures of this species were similar to those described for this species by Johannsen (1937) and by Hamilton (1965), and they could be readily distinguished from other *Dicrotendipes* larvae which occurred in Lake Wabamun. A characteristic which appears to be unique to *D. modestus* and which has not been mentioned in any of the previously cited descriptions of the larvae is the pigmentation pattern on the gular region of the head capsule. The basal one third of the gular region is pigmented on all of the larvae from which *D. modestus* was reared.

Dicrotendipes sp. #1

Notes: The larva of this species is very distinct. The basal antennal segment is as short as that described for *D. lucifer* by Hauber and Morrisey (1945). The labial plate is extremely darkly pigmented and bears teeth that are low, broad, and rounded. The dorso-mesal brown stripe is absent on all of the specimens and the epipharyngeal pecten bears 3 broad and thick teeth rather than 5 as in all of the other species. The pupae and imagines of this species have not been obtained.

Dicrotendipes sp. #2
Dicrotendipes sp. #3

Notes: These 2 species both exhibit dark pigmentation along the entire gular region of their head capsules. With the exception of the fact that species #3 exceeds species #2 in most head capsule measurements, the two types of larvae appear to be very similar. The fact that sp. #2 was only recorded among low growing *Chara* situated on a sand bottom (Station 14) and species #3 was found among thick growths of macrophytes near the two heated discharges, which grew on mud would suggest that these are the larvae of two different species.

Dicrotendipes sp. #4

Notes: Larva (fourth instar), pupa, and male imago were associated by rearing. The larvae of this species were found only on exposed, rocky shorelines. Neither the larva, nor the male imago, fit any of the descriptions of *Dicrotendipes* species available in the literature.

Genus *Einfeldia* Kieffer
Einfeldia pagana (Meigen)

Notes: This species was reared. Although the adult males of this species key to *Tendipes (Einfeldia) paganus* (Meigen) in Townes (1945, pp. 111-112) and are distinct form those described for *Einfeldia synchrona* by Oliver (1971), the larvae of this species are not distinguishable from those of *E. synchrona*.

Einfeldia brunneipennis (Johannsen)

Notes: This species was not reared, but by virtue of the fact that this species is much smaller than *E. pagana*, I am tentatively associating the adults with some small larvae of *Einfeldia* which are about 30% smaller than the ones I reared to *E. pagana*. Both the adults and the larvae are very rare in my collections. On the basis of head capsule measurements of larvae obtained in samples, I am certain that the larvae which I am considering to be *E. brunneipennis* are too large to be third instars of *E. pagana*.

Genus *Endochironomus* Kieffer
Endochironomus nigricans (Johannsen)

Notes: This species was reared and the immature stages resemble those described for the species by Johannsen (1937) and by Roback (1957). The larvae from Lake Wabamun will key to *E. nigricans* using keys contained in both of these references.

Endochironomus subtendens (Townes)

Notes: This species was reared and the immature stages are similar to those described under the name *Chironomus (Endochironomus) viridis* (Malloch) by Johannsen (1937). Townes (1945, p. 65) synonymized *C. viridis* (Malloch) under a new species *Tanytarsus (Endochironomus) subtendens*. The larvae of this species from Lake Wabamun key to *T. (Endochironomus) subtendens* Townes in Roback (1957, pp. 119-120).

Genus *Glyptotendipes* Kieffer
Subgenus *Demeijera* Kruseman
Glyptotendipes (Demeijera) atrimanus (Coquillett)

Notes: *Glyptotendipes atrimanus* was reared. This larva is distinguishable from other *Glyptotendipes* from Lake Wabamun. A description of the immature stages of *G. atrimanus* has never been published.

Subgenus *Phytotendipes* Goetghebuer
Glyptotendipes (Phytotendipes) lobiferus (Say)

Notes: This species was reared and the immature stages are identical to those described for this species by McCauley (1974) from George Lake, Alberta, and to those specimens determined as *G. lobiferus* in the Canadian National Collection. The life history and habitat of *G. lobiferus* in Lake Wabamun appears to be identical to that described for this species by McCauley (1974).

Glyptotendipes (Phytotendipes) paripes (Edwards)

Notes: This species was not reared. Both larvae and adults which fit the descriptions given by McCauley (1974) for *G. paripes* were collected.

Glyptotendipes (Phytotendipes) dreisbachi Townes

Notes: Larvae fitting the description given for this species by McCauley (1974) were caught in the *Typha* marsh near Station 9 which is a similar habitat to that in which the species was found by McCauley at George Lake.

Glyptotendipes (Phytotendipes) baripes (Staeger)

Notes: This species was caught as an adult near the intake canal for the Wabamun power station. No larvae which I would suspect to be this species were found.

Genus *Microtendipes* Kieffer
Microtendipes pedellus (de Geer)

Notes: This species was reared and the immatures were found to be very similar to those already described for this species (Johannsen, 1937 and Hamilton, 1965). The larvae key to *M. pedellus* on Roback's key (1957, p. 108).

Microtendipes sp. #1

Notes: Larvae of a species distinct from *M. pedellus* were collected at Stations 13 and 14. One of these larvae was reared to yield a male imago which is also distinct from *M. pedellus*. The adult males will not key on Townes' key to *Microtendipes* (Townes, 1945, p. 23) and the larvae key to *M. tarsalis* (Walker) on Roback's key (1957, p. 108) by virtue of the fact that they possess 3 light teeth on the median portion of the labial plate, with the median one of the triad very small. Larvae of this type were present in the Canadian National Collection, but were not associated with adults and hence not identified to species.

Genus *Omisus* Townes
Omisus pica Townes

Notes: Only one specimen, an adult male was caught.

Genus *Parachironomus* Lenz
Parachironomus cf. abortivus (Malloch)

Notes: Adult males which keyed to *Harnischia abortiva* were collected (Townes, 1945). With these I have tentatively associated a type of larva which closely resembles those described under the name *Chironomus (Cryptochironomus) parilis* Walker var. *abortivus* Malloch by Johannsen (1937). This species was called *H. abortiva* by Townes. Although similar in most respects the larva is not identical with that described by Johannsen in that the 3 basal segments of the antenna and the labial teeth are not brown.

Parachironomus potamogeti (Townes)

Notes: Many adult males which keyed to *Harnischia potamogeti* on Townes' key to the subgenus *Harnischia* (Townes, 1945, pp. 153-155) were collected, and several *Parachironomus* larvae were reared to imagines of this species. Hamilton (1965) described an identical larva which he had tentatively associated with *Harnischia galaptera*.

Parachironomus sp. #1
Parachironomus sp. #2

Notes: Both of these species were only caught as larvae. They key to *Parachironomus* on Saether's key to larvae of the *Harnischia* complex (Saether, 1977, pp. 93-95).

Genus *Cladopelma* Kieffer
Cladopelma viridula (Fabricius)

Notes: This species was reared. The male imagines resemble those illustrated by Saether (1977, p. 88, Fig. 33). The labial plate of the larva resembles that illustrated for *Harnischia amacheurus* Townes by Roback (1957, Pl. 15, Fig. 314).

Genus *Phaenopsectra* Kieffer
Subgenus *Tribelos* Townes
Phaenopsectra (Tribelos) jucundus var. *dimorphus* (Malloch)

Notes: This species was reared. The immatures of this species fit the description by Johannsen for *Chironomus (Endochironomus) dimorphus* Malloch (Johannsen, 1937, p. 35) and key to *Tanytarsus (Tribelos) jucundus* (Walker) in Roback (1957, p. 119).

Genus *Polypedilum* Kieffer
Subgenus *Tripodura* Townes
Polypedilum (Tripodura) simulans Townes

Notes: This species was not reared, but larvae identical to those described for this species by Hamilton (1965) were found. This plus comparison with other reared specimens of *P. simulans* in the Canadian National Collection permits a fairly probable association of larva and adult for this species. Adult *P. simulans* were collected quite frequently at Lake Wabamun.

Subgenus *Polypedilum* Kieffer

Polypedilum (Polypedilum) nubeculosum (Meigen)

Notes: This species is the most abundant *Polypedilum* in Lake Wabamun and many reared specimens were studied. All stages fit descriptions given by Hamilton (1965) and by Maschwitz (1975).

Polypedilum (Polypedilum) sp. #1

Notes: This species was not individually reared. Adult male imagines were obtained from an aquarium containing macrophytes collected at the lake. The *Polypedilum* larvae found upon these macrophytes were different from any other which occurs within the lake, and hence, it is most probable that they were the larvae of this species. Adult males of this species key to *P. braseniae* (Leathers), but the genitalia are not identical to those illustrated for this species by Townes (1945, Fig. 59). It would seem unlikely that the Lake Wabamun specimens are *P. braseniae* since this species was found by Leathers (1922) to be a miner of the leaves of the pold lily *Brasenia* and *Nymphaea* and *Polypedilum* sp. #1 was observed to build its tubes alongside the stems of *Elodea canadensis*. Furthermore, the larvae which I am almost certain are those of *Polypedilum* sp. #1 have a strikingly different head capsule morphology from those described for *P. braseniae* by Leathers.

Maschwitz (1975) has described a new species of *P. (Polypedilum)* to which both the adults and the suspected larvae of *Polypedilum* sp. #1 are identical.

Subgenus *Pentapedilum* Kieffer

Polypedilum (Pentapedilum) sordens (Wulp)

Notes: This species was reared. The larva keys to *P. sordens* in Roback (1957, p. 115).

Genus *Pseudochironomus* Malloch

Pseudochironomus fulviventris (Johannsen)

Notes: This species was reared, and all stages fit the descriptions for *P. fulviventris* given by Saether (1977, pp. 60-64). Muttkowski (1918) described the habitat of *P. fulviventris* as being sandy and gravelly littoral regions of lakes, and this is exactly the type of habitat within which the larvae can be found at Lake Wabamun.

Pseudochironomus sp. #1

Notes: Larvae which key to *P. ? pseudoviridis* in Saether (1977, p. 64) were found growing on *Chara* from sandy and rocky littoral areas. This species was never reared.

Genus *Stictochironomus* Kieffer

Stictochironomus sp. #1
Stictochironomus sp. #2

Notes: Two distinct types of larvae of this genus were found. Neither were reared. Adult male imagines of *Stictochironomus* were commonly caught, but they could not be identified using Townes' key (1945) to the males of this genus.

Tribe Tanytarsini

Notes: The nearctic Tanytarsini are so little known that none of the species which were taken at Lake Wabamun could be identified to species with certainty.

Genus *Cladotanytarsus* Kieffer

Notes: Four types of *Cladotanytarsus* larvae were found during this study, and all 4 were reared to yield male imagines. Male imagines were compared to illustrations and descriptions given by Malloch (1915) and by Hirvenoja (1962), but none fit the description of any known species. All of the male imagines keyed to the *mancus* species group on an unpublished key to the Tanytarsini by Sublette and Sublette. The larvae of this genus keyed to the group *Atanytarsus* of the genus *Calopsectra* on Roback's (1957, pp. 125-126) key to the Calopsectrini (=Tanytarsini).

Genus *Micropsectra* Kieffer

Notes: Three types of *Micropsectra* larvae were found. These larvae all keyed to group *Micropsectra* using Roback's (1957) key to larval Tanytarsini. The adults of this genus were all keyed to *Micropsectra* species group *nigrapila* on Sublette and Sublette's unpublished key to the Tanytarsini. One of the larval types was reared to yield a male imago which fitted the description of *M. nigrapila* (Johannsen) given by Hauber (1945). Two species including *M. nigrapila* were obtained as adults from shoreline collections.

Genus *Paratanytarsus* Kieffer

Notes: Five types of *Paratanytarsus* larvae were found. These larvae all keyed to the group *Paratanytarsus* using Roback's (1957) key to the larval Tanytarsini. No *Paratanytarsus* larvae were reared to yield imagines, but collections of imagines made along the lakeshore contained 4 species of this genus. These imagines were compared to illustrations and descriptions given by Reiss (1968), but none could be identified as any of the known species of this genus.

Genus *Tanytarsus* van der Wulp

Notes: Larval *Tanytarsus* keyed to the group *Calopsectra* on Roback's (1957) key to the larval Tanytarsini. Nine types of *Tanytarsus* larvae were distingusihed. The two most common of these, *T. cf. xanthus* (sp. #1) and *T. cf. lestagei* (sp. #2), were reared to yield male imagines.

Shoreline collections from Lake Wabamun yielded male imagines of 10 different species of *Tanytarsus*. Many of these resembled species described from nearctic or from palearctic locations, but none fitted perfectly the description of any known species. The breakdown of the species, obtained by keying the Lake Wabamun material on the key of Reiss and Fittkau (1971), is given below.

Tanytarsus chinyensis group near *T. limneticus* (Sublette, 1964)
Tanytarsus eminulus group near *T. lestagei* (Reiss and Fittkau, 1971)
Tanytarsus eminulus group sp. #2
Tanytarsus excavatus group near *T. excavatus* (Reiss and Fittkau, 1971)
Tanytarsus holochlorus group near *T. xanthus* (Sublette, 1964)
Tanytarsus holochlorus group near *T. dendyi* (Sublette, 1964)
Tanytarsus lugens group near *T. lugens* (Reiss and Fittkau, 1971)
Tanytarsus norvegicus group sp.
Tanytarsus veralli group, probably *T. veralli* (Reiss and Fittkau, 1971)
Tanytarsus sp.

The 7 larval types of *Tanytarsus* whose relationships to the imagines are unknown are designated as *Tanytarsus* sp. #3 to #9 in the text.

Tanytarsini (genus undetermined) sp. #1

Notes: Several reared specimens of this species were obtained, and good larval, pupal, and adult material was available for study. This species probably belongs to *Zavrelia*, but the eyes of the imago are only slightly hairy which is in contradiction to the description of *Zavrelia* given by Sublette and Sublette in their unpublished key to the Tanytarsini.

LITERATURE CITED

Baker, F. C. 1945. The molluscan family Planorbidae. Univ. Illinois Press, Urbana.

Betten, C. 1934. The caddisflies or Trichoptera of New York state. N. Y. State Mus. Bull. 292.

Bousfield, E. L. 1958. Fresh-Water Amphipod Crustaceans of Glaciated North America. Can. Field Nat. 72: 55-113.

Brinkhurst, R. O. 1964. Studies on the North American aquatic oligochaeta. I. Naididae and Opistocystidae. Proc. Acad. Nat. Sci. Philad. 116: 95.

_____. 1965. Studies on the North American aquatic oligochaeta. II. Tubificidae. Proc. Acad. Nat. Sci. Philad. 117: 117.

Brinkhurst, R. O., and B. G. M. Jamieson. 1971. Aquatic Oligochaeta of the World. Oliver and Boyd, Edinburgh.

Brundin, L. 1956. Zur Systematik der Orthocladiinae (Dipt. Chironomidae). Inst. of Freshwater Res., Drottningholm Rep. No. 37: 5-185.

Clarke, A. H. 1973. The freshwater molluscs of the Canadian interior basin. Malacologia 13: 1-509.

Cooper, W. E. 1965. Dynamics and production of a natural population of a freshwater amphipod, *Hyalella azteca*. Ecol. Monogr. 35: 377-394.

Davies, R. W. 1971. A key to the freshwater Hirudinoidea of Canada. J. Fish. Res. Board Can. 28: 543-552.

Davies, R. W., and R. P. Everett. 1975. The feeding of four species of freshwater Hirudinoidea in Southern Alberta. Verh. Int. Ver. Limnol. 19: 2816-2827.

Davies, R. W., and T. B. Reynoldson. 1975. Life history of *Helobdella stagnalis* (L.) in Alberta. Verh. Int. Ver. Limnol. 19: 2828-2839.

DeLorme, L. D. 1964. Limnological factors controlling freshwater ostracods. Dept. of Geological Sciences. University of Saskatchewan report.

_____. 1967. Field key and methods of collecting ostracods in Canada. Can. J. Zool. 45: 1275-1281.

_____. 1970a. Freshwater ostracods of Canada. Part I. Subfamily Cypridinae. Can. J. Zool. 48: 153-168.

_____. 1970b. Freshwater ostracods of Canada. Part II. Subfamily Cypridopsinae and Herpetocypridinae and Family Cyclocyprididae. Can. J. Zool. 48: 252-266.

_____. 1970c. Freshwater ostracods of Canada. Part III. Family Candonidae. Can. J. Zool. 48: 1099-1127.

_____. 1970d. Freshwater ostracods of Canada. Part IV. Families Ilyocyprididae, Notodromadidae, Darwinulidae, Cytherideidae, and Entocytheridae. Can. J. Zool. 48: 1251-1259.

_____. 1971. Freshwater ostracods of Canada. Part V. Families Limnmocytheridae, Loxoconchidae. Can. J. Zool. 49: 43-64.

Deevey, E. S. 1941. Limnological Studies in Connecticut. VI. The quantity and composition of the bottom fauna of thirty-six Connecticut and New York lakes. Ecol. Monogr. 11: 413-455.

DeWitt, R. M. 1954. Reproduction, embryonic development, and growth in the pond snail *Physa gyrina* Say. Trans. Amer. Microsc. Soc. 73: 125-137.

_____. 1955. The ecology and life history of the pond snail, *Physa gyrina*. Ecology 36: 40-44.

Edmunds, G. F. Jr., S. L. Jensen, and L. Berner. 1976. The Mayflies of North and Central America. Univ. Minnesota Press, Minneapolis.

Elkins, W. A. 1936. The immature stages of some Minnesota Trichoptera. Ann. Ent. Soc. Am. 29: 656-681.

Ferguson, F. Jr. 1944. Studies on the seasonal life-history of three species of freshwater Ostracoda. Amer. Midl. Nat. 32: 713-727.

Flint, O. S. 1960. Taxonomy and biology of nearctic limnephilid larvae (Trichoptera) with species reference to species in the eastern United States. Entomol. Amer. Brooklyn Entomol. Soc. 40: 1-120.

Folsom, T. C. 1976. An ecological study of *Dugesia tigrina* (Turbellaria: Tricladida) in Lake Wabamun, Alberta, a thermally enriched lake. M.Sc. Thesis, Univ. Alberta, Edmonton.

Gloyd, L. K., and M. Wright. 1959. Odonata in W. T. Edmondson (Ed.) Fresh-water Biology. J. Wiley and Sons. pp. 917-940.

Goodnight, C. J. 1959. Oligochaeta in W. T. Edmondson (Ed.) Fresh-water Biology. J. Wiley and Sons. pp. 522-537.

Hamilton, A. L. 1965. An analysis of a freshwater benthic community with species reference to the Chironomidae. App. II Taxonomy of the Chironomidae of Marion Lake, British Columbia. Ph.D. Thesis, Univ. of British Columbia, Vancouver, B.C.

Hamilton, A. L., O. A. Saether, and D. R. Oliver. 1969. A classification of the nearctic Chironomidae. Fish. Res. Board Can. Tech. Rep. 124.

Hauber, U. A. 1944. Life-histories and ecology of Iowa midges (Tendipedidae) I. The Genus *Tanytarsus*. Proc. Iowa Acad. Sci. 51: 451-461.

_____. 1947. The Tendipedinae of Iowa (Diptera). Amer. Midl. Nat. 38: 456-465.

Hauber, U. A., and T. Morrissey. 1945. Limnochironomids in Iowa including their life histories. Proc. Iowa Acad. Sci. 52: 287-292.

Heard, W. H. 1962. Distribution of Sphaeriidae (Pelecypoda) in Michigan, U.S.A. Malacologia 1: 139-160.

Hirvenoja, M. 1962. Cladotanytarsus - Arten (Dipt.: Chironomidae) aus Finnisch-Lappland. Ann. Ent. Fenn. 28: 173-181.

_____. 1973. Revision der Gattung *Cricotopus* van der Wulp und ihrer Verwandten (Diptera: Chironomidae). Ann. Zool. Fenn. 10: 1-363.

Hyman, L. 1959. Turbellaria: Tricladida in W. T. Edmondson (Ed.) Fresh-water Biology. J. Wiley and Sons. pp. 326-333.

Hynes, H. B. N. 1955. The reproductive cycle of some British freshwater Gammaridae. J. Animal Ecol. 24: 352-387.

Johannsen, O. A. 1905. Aquatic Nematocerous Diptera II. N. Y. State Mus. Bull. 86: Entomol. 23.

_____. 1908. New North American Chironomidae. N. Y. State Mus. Bull. 124: 264-285.

Johannsen, O. A. 1937. Aquatic Diptera. Part III Chironomidae: Subfamilies Tanypodinae, Diamesinae and Orthocladiinae. Mem. Cornell Univ. Agricult. Exp. Sta., Mem. 205.

_____. 1937b. Aquatic Diptera. IV. Chironomidae Subf. Chironominae. Mem. Cornell Univ. Agricult. Exp. Sta., Mem. 210.

Johnston, P. F. 1966. Succession and distribution of Ostracoda in highway borrow pit ponds of Central Alberta. M.Sc. Thesis, Depts. of Zoology and Geology, Univ. Alberta, Edmonton.

Jones, E. R. 1959. Turbellaria: Neorhabdocoela in W. T. Edmondson (Ed.) Fresh-water Biology. J. Wiley and Sons. pp. 341-358.

Leathers, A. L. 1922. Ecological study of aquatic midges and some related insects with special reference to feeding habits. U.S. Bur. Fisheries Bull. 38: 1-61.

Leech, H. B., and M. W. Sanderson. 1959. Coleoptera in W. T. Edmondson (Ed.) Fresh-water Biology. J. Wiley and Sons. pp. 981-1023.

Lenz, F. 1921. Die Metamorphose der *Chironomus*-Gruppe. Morphologie der Larven and Puppen. D. Ent. Zietschr. 1921: 148-162.

Lindeberg, B. 1967. Sibling species delimitation in the *Tanytarsus lestagei* aggregate (Dipt.: Chironomidae). Ann. Zool. Fenn. 4: 45-86.

Malloch, J. R. 1915. The Chironomidae or midges of Illinois, with particular reference to the species occurring in the Illinois River. Ill. State Lab. Nat. Hist., Bull. 10: 275-543.

Maschwitz, P. 1975. A Revision of the Nearctic species of the subgenus *Polypedilum* (Chironomidae: Diptera). Ph.D. Thesis, Univ. of Minnesota.

McCauley, V. J. E. 1974. Life tables for some natural populations of Chironomidae (Diptera) in a *Typha* marsh. Ph.D. Thesis, Dept. of Entomology, Univ. Alberta, Edmonton.

McGregor, D. L. 1969. The reproductive potential, life-history and parasitism of the freshwater ostracod *Darwinula stevensoni* (Brady and Robertson) in J. W. Neale (Ed.) The Taxonomy, Morphology and Ecology of Recent Ostracoda. Oliver and Boyd, Edinburgh. pp. 194-221.

Menon, P. S. 1966. Population ecology of *Gammarus lacustris* Sars in Big Island Lake. Ph.D. Thesis, Univ. Alberta, Edmonton.

Moore, J. E. 1964. Notes on the leeches (Hirudinea) of Alberta. Natur. Hist. Papers, Nat. Mus. Can. 27: 1-15.

_____. 1966. Further notes on Alberta leeches (Hirudinea). Natur. Hist. Papers, Nat. Mus. Can. 32: 1-11.

Muttkowski, R. A. 1918. The fauna of Lake Mendota, a qualitative and quantitative survey with special reference to insects. Trans. Wis. Acad. of Sci., Arts and Lett. 19: 374-482.

Needham, J. G., J. R. Travers, and Y. C. Hsu. 1935. The biology of mayflies with a systematic account of North American species. Classey.

Nimmo, A. P. 1965. A new species of *Psychoglypha* Ross from western Canada, with notes on several other species of Limnephilidae (Trichoptera). Can. J. Zool. 43: 781-787.

_____. 1971. The adult Ryacophilidae and Limnephilidae (Trichoptera) of Alberta and Eastern British Columbia and their post-glacial origin. Quest. Ent. 7: 3-234.

Oliver, D. R. 1971. Description of *Einfeldia synchrona* n. sp. (Diptera: Chironomidae). Can. Entomol. 103: 1591-1595.

______. 1977. *Bicinctus* - group of the genus *Cricotopus* van der Wulp (Diptera: Chironomidae) in the Nearctic with a description of a new species. J. Fish. Res. Board Can. 34: 98-104.

Pagast, F. 1933. Chironomidenstudien. Stettin, Ent. Zeitg. 94: 286-300.

Pankratova, V. 1970. Licinki i kikolki komarov podsemiectra Orthocladiinae Fauny SSSR (Diptera, Chironomidae-Tendipedidae) (Midge larvae and pupae of the subfamily Orthocladiinae of the USSR fauna). Inst. Akad. Nauk SSSR 102: 1-345.

Pennak, R. W. 1953. Fresh-water Invertebrates of the United States. Ronald Press.

Reiss, F. 1968. Ökologische und systematische Untersuchungen an Chironomiden (Diptera) des Bodensees. Ein Beitrag zur lakustrischen Chironomid fauna des nordlichen Alpen vorlandes. Arch. Hydrobiol. 64: 176-323.

Reiss, F., and E. J. Fittkau. 1971. Taxonomie und ökologie europäisch verbreiteter Tanytarsus-Arten (Chironomidae, Diptera). Arch. Hydrobiol. Suppl. 40: 75-200.

Rempel, J. G. 1936. The life-history and morphology of *Chironomus hyperboreus*. J. Biol. Bd. Can. 2: 209-221.

Roback, S. S. 1953. Savannah River Tendipedid larvae (Diptera: Tendipedidae=Chironomidae). Proc. Acad. Nat. Sci. Philad. 105: 91-132.

______. 1957. The immature tendepedids of the Philadelphia area. Monogr. Acad. Nat. Sci. Philad. 9: 1-152.

Roback, S. S. 1969. The immature stages of the genus *Tanypus* Meigen (Diptera: Chironomidae, Tanypodinae). Trans. Amer. Entomol. Soc. 94: 407-428.

_____. 1971. The adults of the subfamily Tanypodinae (= Pelopiinae) in North America (Diptera: Chironomidae). Monogr. 17. Acad. Nat. Sci. Philad.

Ross, H. H. 1944. The caddis flies or Trichoptera of Illinois. Bull. Ill. Nat. Hist. Surv. 23: 1-326.

Saether, O. A. 1969. Some nearctic Podonominae, Diamesinae, and Orthocladiinae (Diptera: Chironomidae). Bull. Fish. Res. Board Can. 170.

_____. 1975a. Nearctic and Palearctic *Heterotrissocladius* Spärck (Diptera: Chironomidae). Bull. Fish. Res. Board Can. 193.

_____. 1975b. Nearctic chironomids as indicators of lake typology. Verh. Int. Ver. Limnol. 19: 3127-3133.

_____. 1976. Revision of *Hydrobaenus*, *Trissocladius*, *Zalutschia*, *Paratrissocladius*, and some related genera (Diptera: Chironomidae). Bull. Fish. Res. Board Can. 195.

_____. 1977. Female genitalia in Chironomidae and other Nematocera: morphology, phylogenies, keys. Bull. Fish. Res. Board Can. 197.

_____. 1977b. Taxonomic studies on Chironomidae: *Nanocladius*, *Pseudochironomus*, and the *Harnischia* complex. Bull. Fish. Res. Board Can. 196.

Sankurathri, C. S., and J. C. Holmes. 1976. Effects of thermal effluent on the population dynamics of *Physa gyrina* Say (Mollusca: Gastropoda) at Lake Wabamun, Alberta. Can. J. Zool. 54: 582-590.

Saponis, A. R. 1977. A revision of the nearctic species of *Orthocladius (Orthocladius)* van der Wulp (Diptera: Chironomidae). Mem. of the Entomological Society of Canada. No. 102.

Søgaard-Andersen, F. 1937. Über die Metamorphose der Ceratopogoniden und Chironomiden Nordöst-Grönlands. Medd. Grønland 116: 1-94.

Stewart, P. L., and J. S. Loch. 1973. A guide for the identification of two subfamilies of larval chironomidae: The Chironominae and Tanypodinae found in benthic studies in the Winnipeg River in the vicinity of Pine Falls, Manitoba in 1971 and 1972. Dept. of Environment, Fisheries and Marine Service, Fisheries Operations Directorate Technical Report Series No. CEN/T-73-12.

Sublette, J. E. 1964. Chironomidae (Diptera) of Louisiana I. Systematic and immature stages of some lentic chironomids of west-central Louisiana. Tulane Stud. in Zool. 11: 109-150.

Sublette, J. E., and M. F. Sublette. 1974. A review of the genus *Chironomus* (Diptera: Chironomidae) V. The *maturus* complex. Stud. Nat. Sci. Portales, New Mexico Vol. 1: 1-40.

_____. unpubl. A review of the genera of Tanytarsini of the world.

Thienemann, A. 1944. Bestimmungstabellen für die bis jetzt bekannten Larven und Puppen der Orthocladiinae. Arch. Hydrobiol. 39: 551-664.

_____. 1954. *Chironomus:* Leben, Verbreitung und Wirtschaftliche Bedeutung der Chironomiden. Die Binnengewässer 20.

Thomsen, L. C. 1937. Ceratopogonidae in Aquatic Diptera Pt. V Cornell Univ. Agr. Exp. Sta., Mem. 210.

Townes, H. K. 1945. The nearctic species of Tendipedini (Diptera; Tendipedidae = Chironomidae). Amer. Midl. Nat. 34: 1-206.

Tressler, W. L. 1959. Ostracoda in W. T. Edmondson (Ed.) Freshwater Biology. J. Wiley and Sons, New York. pp. 657-734.

Vorhies, C. T. 1909. Studies on the Trichoptera of Wisconsin. Trans. Wis. Acad. of Sci., Arts and Lett. 16: 647-738.

Walker, E. M. 1953. The Odonata of Canada and Alaska. Vol. I. Toronto Univ. Press.

_____. 1958. The Odonata of Canada and Alaska. Vol. II. Toronto Univ. Press.

Walker, E. M., and P. S. Corbet. 1975. The Odonata of Canada and Alaska. Vol. III. Toronto Univ. Press.

Wiggins, G. B. 1960. A preliminary systematic study of the North American larvae of the caddisfly family Phryganeidae (Trichoptera). Can. J. Zool. 38: 1153-1170.

_____. 1977. Larvae of the North American Caddisfly genera (Trichoptera). Toronto Univ. Press.

Winterbourn, M. J. 1971. The life-histories and trophic relationships of the Trichoptera of Marion Lake, British Columbia. Can. J. Zool. 49: 623-636.

Yamamoto, T., and G. B. Wiggins. 1964. A comparative study of the North American species in the caddisfly genus *Mystacides* (Trichoptera: Leptoceridae). Can. J. Zool. 42: 1105-1126.